Fuel injection

Fuel injection is a means of metering fuel into an internal combustion engine. In modern automotive applications, fuel metering is one of several functions performed by an "engine management system".

For gasoline engines, carburetors were the predominant method to meter fuel before the widespread use of fuel injection. However, a wide variety of injection systems have existed since the earliest usage of the internal combustion engine.

The primary functional difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on the vacuum created by intake air rushing through it to add the fuel to the airstream.

The fuel injector is only a nozzle and a valve: the power to inject the fuel comes from further back in the fuel supply, from a pump or a pressure container.

Objectives

The functional objectives for fuel injection systems can vary. All share the central task of supplying fuel to the combustion process, but it is a design decision how a particular system will be optimized. There are several competing objectives such as:

- power output
- fuel efficiency
- emissions performance
- ability to accommodate alternative fuels
- durability
- reliability
- driveability and smooth operation
- initial cost
- maintenance cost
- diagnostic capability
- range of environmental operation

Certain combinations of these goals are conflicting, and it is impractical for a single engine control system to fully optimize all criteria simultaneously. In practice, automotive engineers strive to best satisfy a customer's needs competitively. The modern digital electronic fuel injection system is far more capable at optimizing these competing objectives than a carburetor.

Benefits

Engine operation

Operational benefits to the driver of a fuel-injected car include smoother and more dependable engine response during quick throttle transitions, easier and more dependable engine starting, better operation at extremely high or low ambient temperatures, reduced maintenance intervals, and increased fuel efficiency.

An engine's air/fuel ratio must be accurately controlled under all operating conditions to achieve the desired engine performance, emissions, driveability, and fuel economy. Modern electronic fuel injection systems meter fuel very accurately and precisely, and closed loop fuel control based on feedback from an oxygen sensor (or "O2 sensor") lets fuel-injected engines run considerably cleaner than comparable carbureted engines. Properly-designed fuel injection systems can react faster and more precisely to rapidly changing inputs such as rapid throttle movements, and can tailor fuel distribution to closely match the engine's needs across a wider range of operating conditions such as load, ambient temperature, operating temperature, fuel quality, and altitude (*i.e.,* barometric pressure).

Emissions, efficiency, and power

Fuel injection generally delivers a more accurate and equal mass of fuel to each cylinder of the engine than can a carburetor, thus improving the cylinder-to-cylinder distribution. Exhaust emissions are cleaner, not only because the more precise and accurate fuel metering reduces the concentration of toxic chemicals leaving the engine, but also because exhaust cleanup devices such as the catalytic converter can be optimized to operate much more efficiently given exhaust of precise and predictable composition.

Fuel injection generally increases engine efficiency. With the improved cylinder-to-cylinder fuel distribution provided by fuel injection, less fuel is needed for the same power output. When cylinder-to-cylinder distribution is less than ideal, as is always the case to some degree, some cylinders receive excess fuel as a side effect of ensuring that all cylinders receive *sufficient* fuel. Power output is asymmetrical with respect to air/fuel ratio; burning extra fuel in the rich cylinders does not reduce power nearly as quickly as burning too little fuel in the lean cylinders. However, rich-running cylinders are undesirable from the standpoint of exhaust emissions, fuel efficiency, engine wear, and engine oil contamination. Deviations from perfect air/fuel distribution, however subtle, affect the emissions, by not letting the combustion events be at the chemically ideal (stoichiometric) air/fuel ratio. Grosser distribution problems eventually begin to reduce efficiency, and the grossest distribution issues finally affect power. Increasingly poorer air/fuel distribution affects emissions, efficiency, and power, in that order. By optimizing the homogeneity of cylinder-to-cylinder mixture distribution, all the cylinders approach their maximum power potential and the engine's overall power output improves.

A fuel-injected engine often produces more power than an equivalent carbureted engine. Fuel injection alone does not necessarily increase an engine's maximum potential output, for increased airflow is needed to burn more fuel to generate more heat to generate more output. The combustion process converts the fuel's chemical energy into heat energy, whether the fuel is supplied by fuel injectors or a carburetor. However, airflow is often improved with fuel injection, the components of which allow more design freedom to improve the air's path into the engine. In contrast, a carburetor's mounting options are limited because it is larger, it must be carefully oriented with respect to gravity, and it must be equidistant from each of the engine's cylinders to the maximum practicable degree. These design constraints generally compromise airflow into the engine. Furthermore, a carburetor relies on a drag-inducing venturi to create a local air pressure difference, which forces the fuel into the air stream. The flow loss caused by the venturi, however, is small compared to other flow losses in the induction system. In a well-designed carburetor induction system, the venturi is not a significant airflow restriction. Aside from airflow considerations, fuel injection offers a more homogeneous air/fuel mixture due to better atomization of the fuel entering the cylinders.

History and development

Frederick William Lanchester joined the Forward Gas Engine Company Birmingham, England in 1889. He carried out what were possibly the earliest experiments with fuel injection.

Fuel injection has been used commercially in diesel engines since the mid 1920s. The concept was adapted for use in petrol-powered aircraft during World War II, and direct injection was employed in some notable designs like the Daimler-Benz DB 603 and later versions of the Wright R-3350 used in the B-29 Superfortress.

One of the first commercial gasoline injection systems was a mechanical system developed by Bosch and introduced in 1955 on the Mercedes-Benz 300SL.

In 1957, Chevrolet introduced a mechanical fuel injection option, made by General Motors' Rochester division, for its 283 V8 engine. This system directed the inducted engine air across a "spoon shaped" plunger, which moved in proportion to the air volume. The plunger connected to the fuel metering system which mechanically dispensed fuel to the cylinders via distribution tubes. This engine produced 283 hp (211 kW) from 283 in³ (4.6 L), making it one of the first production engines in history to exceed 1 hp/in³ (45.5 kW/L), after Chrysler's Hemi engine and a number of others. In another approach, Mercedes' used six individual plungers to feed fuel to each of the six cylinders.

During the 1960s, other mechanical injection systems such as Hilborn were occasionally used on modified American V8 engines in various racing applications such as drag racing, oval racing, and road racing. These racing-derived systems were not suitable for everyday street use.

One of the first electronic fuel injection system was **Electrojector**, developed by the Bendix Corporation. In 1957, AMC was to offer a special edition Rambler Rebel with a 288 horsepower 327 in³ (5.4 L) engine optionally equipped with Electrojector.[citation needed] This was to have been the first production EFI engine, but Electrojector's teething problems meant only a few cars were so equipped, and all are thought to have been retrofitted with 4-barrel carburetors before they were first sold.[specify] Chrysler offered Electrojector on the 1958 DeSoto Adventurer, arguably the first series-production car equipped with a throttle body EFI system, but the early electronic components weren't equal to the rigors of underhood service, and were too slow to keep up with the demands of "on the fly" engine control. Most vehicles originally so equipped were field-retrofitted with 4-barrel carburetors. The Electrojector patents were subsequently sold to Bosch.

Bosch developed an electronic fuel injection system, called **D-Jetronic** (D for Druck, the German word for pressure), which was first used on the VW 1600TL in 1967. This was a speed/density system, using engine speed and intake manifold air density to calculate "air mass" flow rate and thus fuel requirements. The system used all analog, discrete electronics, and an electro-mechanical pressure sensor. The sensor was susceptible to vibration and dirt. This system was adopted by VW, Mercedes-Benz, Porsche, Citroën, Saab and Volvo. Lucas licensed the system for production with Jaguar.

Bosch superseded the D-Jetronic system with the **K-Jetronic** and **L-Jetronic** systems for 1974, though some cars (such as the Volvo 164) continued using D-Jetronic for the following several years, and General Motors installed a very close copy of D-Jetronic on Cadillacs starting in 1977. L-Jetronic first appeared on the 1974 Porsche 914, and uses a mechanical airflow meter (L for Luft, German for air) which produces a signal that is proportional to "air volume". This approach required additional sensors to measure the barometer and temperature, to ultimately calculate "air mass". L-Jetronic was widely adopted on European cars of that period, and a few Japanese models a short time later.

In 1982, Bosch introduced a sensor that directly measures the air mass flow into the engine, on their L-Jetronic system. Bosch called this **LH-Jetronic** (L for Luftmasse, or air, and H for Hitzdraht, or hot-wire). The mass air sensor utilizes a heated platinum wire placed in the incoming air flow. The rate of the wire's cooling is proportional to the air mass flowing across the wire. Since the hot wire sensor directly measures air mass, the need for additional temperature and pressure sensors is eliminated. The LH-Jetronic system was also the first fully digital EFI system, which is now the standard approach. The advent of the digital microprocessor permitted the integration of all powertrain sub-systems into a single control module.

Supersession of carburetors

Throughout the 1950s and 1960s, various federal, state and local governments conducted studies into the numerous sources of air pollution. These studies ultimately attributed a significant portion of air pollution to the automobile, and concluded air pollution is not bounded by local political boundaries. At that time, such minimal emission control regulations as existed were promulgated at the municipal or, occasionally, the state level. The ineffective local regulations were gradually supplanted by more comprehensive state and federal regulations. By 1967 the state of California (Governor Reagan), created the California Air Resources Board, and in 1970, the U.S. Environmental Protection Agency was formed. Both agencies now create and enforce emission regulations for automobiles, as well as for many other sources. Similar agencies and regulations were contemporaneously developed and implemented in Europe, Australia, and Japan.

The ultimate combustion goal is to match each molecule of fuel with a corresponding number of molecules of oxygen so that neither has any molecules remaining after combustion in the engine and catalytic converter. Such a balanced condition is known as stoichiometry. Extensive carburetor modifications and complexities were needed to approach stoichiometric engine operation in order to comply with increasingly-strict US exhaust emission regulations of the 1970s and 1980s. This increase in complexity gradually eroded and then reversed the simplicity, cost, and packaging advantages carburetors had traditionally offered.

Fuel injection appeared first as novelty equipment on American-made cars in the late 1950s, such as the 1958 Chrysler products equipped with Bendix' ElectroJector, and 1957–1965 Rochester fuel injected Chevrolet Corvettes. About a decade later, more practical fuel injection systems were introduced in European-made cars. As emission regulations progressively tightened worldwide, generally led by the US state of California's especially stringent rules, automakers had to improve the precision and accuracy with which fuel was metered to the engine. Catalytic converters also became practically universal equipment.

There are three primary types of toxic emissions from an internal combustion engine: Carbon Monoxide (CO), unburnt hydrocarbons (HC), and oxides of nitrogen (NOx). CO and HC result from incomplete combustion of fuel due to insufficient oxygen in the combustion chamber. NOx, in contrast, results from excessive oxygen in the combustion chamber. The opposite causes of these pollutants makes it difficult to control all three simultaneously. Once the permissible emission levels dropped below a certain point, catalytic treatment of these three main pollutants became necessary. This required a particularly large increase in fuel metering accuracy and precision, for simultaneous catalysis of all three pollutants requires that the fuel/air ratio be held within a very narrow range of stoichiometry. The open loop fuel injection systems had already improved cylinder-to-cylinder fuel distribution and engine operation over a wide temperature range, but did not offer sufficient fuel/air ratio control to enable effective exhaust catalysis. **Closed loop** fuel injection systems improved the air/fuel ratio control with an exhaust gas oxygen sensor. The O_2 sensor is mounted in the exhaust system upstream of the catalytic converter, and enables the engine management computer to determine and adjust the air/fuel ratio precisely and quickly.

Fuel injection was phased in through the latter '70s and '80s at an accelerating rate, with the US and German markets leading and the UK and Commonwealth markets lagging somewhat, and since the early 1990s, almost all gasoline passenger cars sold in first world markets like the United States, Europe, Japan, and Australia have come equipped with electronic fuel injection (EFI). Many motorcycles still utilize carbureted engines, though all current high-performance designs have switched to EFI.

Fuel injection systems have evolved significantly since the mid 1980s. Current systems provide an accurate, reliable and cost-effective method of metering fuel and providing maximum engine efficiency with clean exhaust emissions, which is why EFI systems have replaced carburetors in the marketplace. EFI is becoming more reliable and less expensive through widespread usage. At the same time, carburetors are becoming less available, and more expensive. Even marine applications are adopting EFI as reliability improves. Virtually all internal combustion engines, including motorcycles, off-road vehicles, and outdoor power equipment, may eventually use some form of fuel injection.

It should be noted that carburetion remains a less costly alternative where strict emission regulations and advanced vehicle diagnostic and repair infrastructure do not exist, as in developing countries. Fuel injection is gradually replacing carburetors in these nations too as they adopt emission regulations conceptually similar to those in force in Europe, Japan, Australia and North America.

Basic function

The process of determining the amount of fuel, and its delivery into the engine, are known as fuel metering. Early injection systems used mechanical methods to meter fuel (non electronic, or mechanical fuel injection). Modern systems are nearly all electronic, and use an electronic solenoid (the injector) to inject the fuel. An electronic engine control unit calculates the mass of fuel to inject.

Modern fuel injection schemes follow much the same setup. There is a mass airflow sensor or manifold absolute pressure sensor at the intake, typically mounted either in the air tube feeding from the air filter box to the throttle body, or mounted directly to the throttle body itself. The mass airflow sensor does exactly what its name implies; it senses the mass of the air that flows past it, giving the computer an accurate idea of how much air is entering the engine. The next component in line is the Throttle Body. The throttle body has a throttle position sensor mounted onto it, typically on the butterfly valve of the throttle body. The throttle position sensor (TPS) reports to the computer the position of the throttle butterfly valve, which the ECM uses to calculate the load upon the engine. The fuel system consists of a fuel pump (typically mounted in-tank), a fuel pressure regulator, fuel lines (composed of either high strength plastic, metal, or reinforced rubber), a fuel rail that the injectors connect to, and the fuel injector(s). There is a coolant temperature sensor that reports the engine temperature to the ECM, which the engine uses to calculate the proper fuel ratio required. In sequential fuel injection systems there is a camshaft position sensor, which the ECM uses to determine which fuel injector to fire. The last component is the oxygen sensor. After the vehicle has warmed up, it uses the signal from the oxygen sensor to perform fine tuning of the fuel trim.

The fuel injector acts as the fuel-dispensing nozzle. It injects liquid fuel directly into the engine's air stream. In almost all cases this requires an external pump. The pump and injector are only two of several components in a complete fuel injection system.

In contrast to an EFI system, a carburetor directs the induction air through a venturi, which generates a minute difference in air pressure. The minute air pressure differences both emulsify (premix fuel with air) the fuel, and then acts as the force to push the mixture from the carburetor nozzle into the induction air stream. As more air enters the engine, a greater pressure difference is generated, and more fuel is metered into the engine. A carburetor is a self-contained fuel metering system, and is cost competitive when compared to a complete EFI system.

An EFI system requires several peripheral components in addition to the injector(s), in order to duplicate all the functions of a carburetor. A point worth noting during times of fuel metering repair is that early EFI systems are prone to diagnostic ambiguity. A single carburetor replacement can accomplish what might require numerous repair attempts to identify which one of the several EFI system components is malfunctioning. Newer EFI systems since the advent of OBD II diagnostic systems, can be very easy to diagnose due to the increased ability to monitor the realtime data streams from the individual sensors. This gives the diagnosing technician realtime feedback as to the cause of the drivability concern, and can dramatically shorten the number of diagnostic steps required to ascertain the cause of failure, something which isn't as simple to do with a carburetor. On the other hand, EFI systems require little regular maintenance; a carburetor typically requires seasonal and/or altitude adjustments.

[edit] Type of fuel

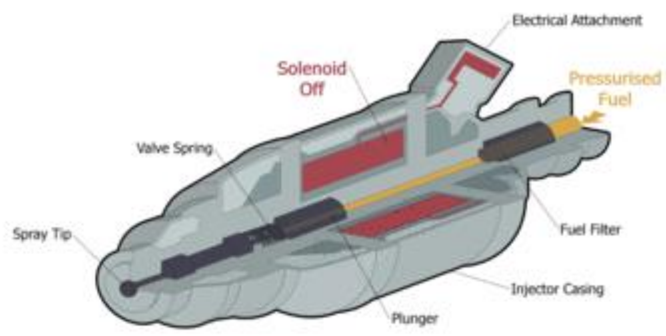
A fuel injection system is designed and calibrated specifically for the type(s) of fuel it will handle: Autogas (LPG, also known as propane), gasoline (petrol), ethanol, methanol, methane (natural gas), hydrogen or diesel. The majority of fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection, the diesel and gasoline hardware has become quite similar. EFI's programmable firmware has permitted common hardware to be used with multiple different fuels.

- Diesel Fuel
  - At one time, nearly all diesel engines used high-pressure, purely mechanical injection, without electronic control. Present diesels are rapidly adopting EFI, which is based on an electronic fuel injector similar in basic construction to a modern gasoline injector, although using considerably higher injection pressures.
- Gasoline Fuel
  - Prior to 1969, it was rare for a gasoline engine to be equipped with fuel injection, and those few extant systems were generally low-pressure mechanical designs incorporating rather primitive technology. These early systems were generally used on exotic performance vehicles, such as the early V8 powered Corvettes, or for racing.
  - Robert Bosch GmbH, and Bendix introduced the first electronic injection systems starting in the 1950s, and they formed the conceptual basis of today's EFI control strategies. (#Evolution)
- Alternative Fuels (autogas (LPG), ethanol, methanol, natural gas, hydrogen)
  - The basic components of a gasoline EFI system can also be used with some alternative fuels, with appropriate modification. Unique fuel metering values (the calibration contained within the software instructions) are required to accommodate each type of fuel. Virtually all flexible-fuel vehicles use electronic fuel injection. With gaseous fuels, some system components are of completely different design but are similar in operating principle.

Detailed function

Note: These examples specifically apply to a modern EFI gasoline engine. Parallels to fuels other than gasoline can be made, but only conceptually.

Typical EFI components



Animated cut through diagram of a typical fuel injector.

- Injectors
- Fuel Pump
- Fuel Pressure Regulator
- ECM - Engine Control Module; includes a digital computer and circuitry to communicate with sensors and control outputs.
- Wiring Harness
- Various Sensors (Some of the sensors required are listed here.)

  - Crank/Cam Position: Hall effect sensor
  - Airflow: MAF sensor, sometimes this is inferred with a MAP sensor
  - Exhaust Gas Oxygen: Oxygen sensor, EGO sensor, UEGO sensor

Functional description

Central to an EFI system is a computer called the Engine Control Unit (ECU), which monitors engine operating parameters via various sensors. The ECU interprets these parameters in order to calculate the appropriate amount of fuel to be injected, among other tasks, and controls engine operation by manipulating fuel and/or air flow as well as other variables. The optimum amount of injected fuel depends on conditions such as engine and ambient temperatures, engine speed and workload, and exhaust gas composition.

The electronic fuel injector is normally closed, and opens to inject pressurised fuel as long as electricity is applied to the injector's solenoid coil. The duration of this operation, called *pulse width,* is proportional to the amount of fuel desired. The electric pulse may be applied in closely-controlled sequence with the valve events on each individual cylinder (in a **sequential** fuel injection system), or in groups of less than the total number of injectors (in a **batch fire** system).

Since the nature of fuel injection dispenses fuel in discrete amounts, and since the nature of the 4-stroke-cycle engine has discrete induction (air-intake) events, the ECU calculates fuel in discrete amounts. In a sequential system, the injected fuel mass is tailored for each individual induction event. Every induction event, of every cylinder, of the entire engine, is a separate fuel mass calculation, and each injector receives a unique pulse width based on that cylinder's fuel requirements.

It is necessary to know the mass of air the engine "breathes" during each induction event. This is proportional to the intake manifold's air pressure/temperature, which is proportional to throttle position. The amount of air inducted in each intake event is known as "air-charge", and this can be determined using several methods. (See MAF sensor, and MAP sensor.)

The three elemental ingredients for combustion are fuel, air and ignition. However, complete combustion can only occur if the air and fuel is present in the exact stoichiometric ratio, which allows all the carbon and hydrogen from the fuel to combine with all the oxygen in the air, with no undesirable polluting leftovers. Oxygen sensors monitor the amount of oxygen in the exhaust, and the ECU uses this information to adjust the air-to-fuel ratio in real-time.

To achieve stoichiometry, the air mass flow into the engine is measured and multiplied by the stoichiometric air/fuel ratio 14.64:1 (by weight) for gasoline. The required fuel mass that must be injected into the engine is then translated to the required pulse width for the fuel injector. The stoichiometric ratio changes as a function of the fuel; diesel, gasoline, ethanol, methanol, propane, methane (natural gas), or hydrogen.

Deviations from stoichiometry are required during non-standard operating conditions such as heavy load, or cold operation, in which case, the mixture ratio can range from 10:1 to 18:1 (for gasoline).

Pulse width is inversely related to pressure difference across the injector inlet and outlet. For example, if the fuel line pressure increases (injector inlet), or the manifold pressure decreases (injector outlet), a smaller pulse width will admit the same fuel. Fuel injectors are available in various sizes and spray characteristics as well. Compensation for these and many other factors are programmed into the ECU's software.

Sample pulsewidth calculations

Note: These calculations are based on a 4-stroke-cycle, 5.0L, V-8, gasoline engine. The variables used are real data.

Calculate injector pulsewidth from airflow

First the CPU determines the air mass flow rate from the sensors - lb-air/min. *(The various methods to determine airflow are beyond the scope of this topic. See MAF sensor, or MAP sensor.)*

- (lb-air/min) × (min/rev) × (rev/4-strokes-per-cycle) = (lb-air/intake-stroke) = (air-charge)

- min/rev is the reciprocal of engine speed (RPM) – minutes cancel.
- rev/2-revs-per-cycle for an 8 cylinder 4-stroke-cycle engine.

- (lb-air/intake-stroke) × (fuel/air) = (lb-fuel/intake-stroke)

- fuel/air is the desired mixture ratio, usually stoichiometric, but often different depending on operating conditions.

- (lb-fuel/intake-stroke) × (1/injector-size) = (pulsewidth/intake-stroke)

- injector-size is the flow capacity of the injector, which in this example is 24-lbs/hour if the fuel pressure across the injector is 40 psi.
Combining the above three terms . . .

- (lbs-air/min) × (min/rev) × (rev/4-strokes) × (fuel/air) × (1/injector-size) = (pulsewidth/intake-stroke)

Substituting real variables for the 5.0L engine at idle.

- (0.55 lb-air/min) × (min/700 rev) × (rev/4-strokes-per-cycle) × (1/14.64) × (h/24-lb) × (3,600,000 ms/h) = (4.0 ms/intake-stroke)

Substituting real variables for the 5.0 L engine at maximum power.

- (28 lb-air/min) × (min/5500 rev) × (rev/4-strokes-per-cycle) × (1/11.00) × (h/24-lb) × (3,600,000 ms/h) = (34.6 ms/intake-stroke)

Injector pulsewidth typically ranges from 4 ms/engine-cycle at idle, to 35 ms/engine-cycle at wide-open throttle. The pulsewidth accuracy is approximately 0.01 ms; injectors are very precise devices.

Calculate fuel-flow rate from pulsewidth

- (Fuel flow rate) ≈ (pulsewidth) × (engine speed) × (number of fuel injectors)

Looking at it another way:

- (Fuel flow rate) ≈ (throttle position) × (rpm) × (cylinders)

Looking at it another way:

- (Fuel flow rate) ≈ (air-charge) × (fuel/air) × (rpm) × (cylinders)

Substituting real variables for the 5.0 L engine at idle.

- (Fuel flow rate) = (2.0 ms/intake-stroke) × (hour/3,600,000 ms) × (24 lb-fuel/hour) × (4-intake-stroke/rev) × (700 rev/min) × (60 min/h) = (2.24 lb/h)

Substituting real variables for the 5.0L engine at maximum power.

- (Fuel flow rate) = (17.3 ms/intake-stroke) × (hour/3,600,000-ms) × (24 lb/h fuel) × (4-intake-stroke/rev) × (5500-rev/min) × (60-min/hour) = (152 lb/h)

The fuel consumption rate is 68 times greater at maximum engine output than at idle. This dynamic range of fuel flow is typical of a naturally aspirated passenger car engine. The dynamic range is greater on a supercharged or turbocharged engine. It is interesting to note that 15 gallons of gasoline will be consumed in 37 minutes if maximum output is sustained. On the other hand, this engine could continuously idle for almost 42 hours on the same 15 gallons.

Various injection schemes


GM Throttle Body Injection unit

[edit] Throttle body injection

Throttle-body injection (called **TBI** by General Motors and **Central Fuel Injection** (**CFI**) by Ford) or **monopoint injection** was introduced in the mid-1980s as a transition technology toward individual port injection. The TBI system injects fuel at the throttle body (the same location where a carburetor introduced fuel). The induction mixture passes through the intake runners like a carburetor system. The justification for the TBI/CFI phase was low cost. Many of the carburetor's supporting components could be reused such as the air cleaner, intake manifold, and fuel line routing. This postponed the redesign and tooling costs of these components. Most of these components were later redesigned for the next phase of fuel injection's evolution, which is individual port injection, commonly known as EFI. TBI was used briefly on passenger cars and Jeeps during the mid-1980s, and by GM on heavy duty trucks all the way through OBD-I (ending in 1995).

Continuous injection

Bosch's **K-Jetronic** (K stands for kontinuierlich, or continuous) was introduced in 1974. In this system, fuel sprays constantly from the injectors, rather than being pulsed in time with the engine's intake strokes. Gasoline is pumped from the fuel tank to a large control valve called a *fuel distributor*, which separates the single fuel supply pipe from the tank into smaller pipes, one for each injector. The fuel distributor is mounted atop a control vane through which all intake air must pass, and the system works by varying fuel volume supplied to the injectors based on the angle of the air vane, which in turn is determined by the volume flowrate of air past the vane. The injectors are simple spring-loaded check valves with nozzles; once fuel system pressure becomes high enough to overcome the counterspring, the injectors begin spraying. K-Jetronic was used for many years between 1974 and the mid 1990s by Lamborghini, Ferrari, Mercedes-Benz, Volkswagen, Ford, Porsche, Audi, Saab, and Volvo. There was also a variant of the system called KE-Jetronic with electronic trim, able to use a catalytic converter.

Central port injection (CPI)

General Motors developed an "in-between" technique called "central port injection" (**CPI**) or "central port fuel injection" (**CPFI**). It uses tubes with poppet valves from a central injector to spray fuel at each intake port rather than the central throttle-body. This system tends to have a high failure rate and repair is fairly easy. The 2 models used were CPFI from 1992 to 1995, and CSFI from 1996 and on. On early CPI (CPFI) systems fuel is continuously injected to all ports simultaneously also called "batch fire", which is less than optimal. On 1996 and later CSFI systems the fuel is sprayed sequentially as the name implies "Centralized Sequential Fuel Injection".

Multi-point fuel injection

Multi-point fuel injection injects fuel into the intake port just upstream of the cylinder's intake valve, rather than at a central point within an intake manifold, referred to as **SPFI**, or single point fuel injection. MPFI systems can be **sequential**, in which injection is timed to coincide with each cylinder's intake stroke, **batched**, in which fuel is injected to the cylinders in groups, without precise synchronisation to any particular cylinder's intake stroke, or **Simultaneous**, in which fuel is injected at the same time to all the cylinders.

All modern EFI systems utilize sequential MPFI. Some Toyotas and other Japanese cars from the 1970s to the early 1990s used an application of Bosch's multipoint L-Jetronic system manufactured under license by DENSO.

Direct injection

Many diesel engines feature **direct injection** (**DI**). The injection nozzle is placed inside the combustion chamber and the piston incorporates a depression (often toroidal) where initial combustion takes place. Direct injection diesel engines are generally more efficient and cleaner than indirect injection engines. See also High-pressure Direct Injection (HDi) .

Some recent petrol engines utilize direct injection as well. Volkswagen and Audi (FSI) (for *Fuel Stratified Injection*), Mitsubishi(GDI), Mazda(DISI), Ford(DISI), BMW, Saab, Saturn, Lexus and GM. This is the next step in evolution from multi port fuel injection and offers another magnitude of emission control by eliminating the "wet" portion of the induction system. *See also: Gasoline Direct Injection*

[Maintenance hazards

Fuel injection introduces extra hazards in engine maintenance due to the high fuel pressures used. Residual pressure can remain in the fuel lines long after a car has last been used, which requires care to catch any spray when disconnecting a fuel hose. If a high-pressure diesel fuel injector is removed from its seat and operated in open air, there is a risk to the operator of injury by hypodermic injection.[*citation needed*]