Technology factsheets_transport

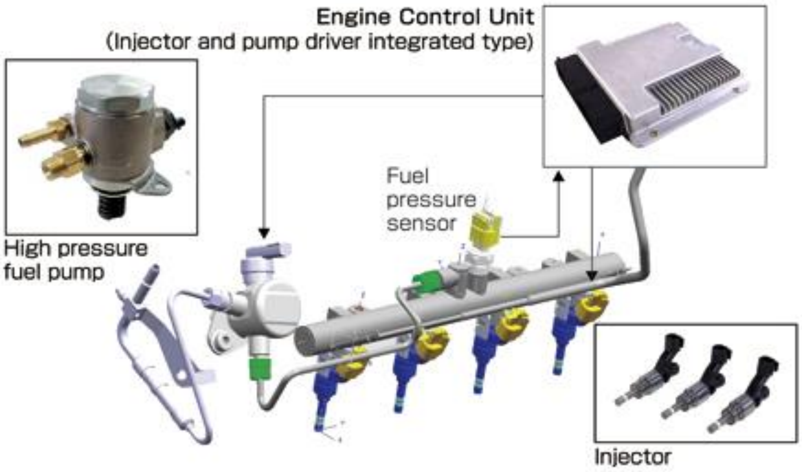
Direct (fuel) Injection System

Defining characteristics	*Narrative*
General	Modern light- and heavy-duty road vehicles are predominantly powered by internal combustion engines (ICEs) running on energy-dense fuels such as petrol[88] or diesel. Essentially, ICEs rely on the synchronous operation of air-supply and fuel-supply sub-systems. In a vehicle running on petrol, a carburetor, historically, represents the intersection of these two sub-systems, vaporises the fuel stream thus allowing it to mix with an incoming airstream before induction into the engine cylinders where combustion generates a motive force that drives the vehicle's powertrain. With environmental concerns gaining traction on the global policy agenda, and environmental standards driving technological innovations on several fronts, fuel injector systems were first introduced as substitutes for carburetors by the automobile industry in the 1980s. One type of fuel injection system; port fuel injection or indirect fuel injection system, works by spraying a mist of fuel through a small nozzle at a pressure of 2.5 to 4.5 bars over the intake valve head where the fuel mist mixes with air in specific proportions, ideally 14.7 parts of air to 1 part of fuel by mass, in readiness for combustion inside engine cylinders. A second type of injection system, conceptually associated with diesel engines, sprays with precise timing an ultra-fine mist of fuel directly into individual engine cylinders. The main benefits to an electrically operated and electronically controlled direct injection system is that at all times a vehicle is on the road, a finely calibrated amount of fuel can be injected into its engine cylinders in response to the engine's operating conditions, resulting in higher power output, improved fuel efficiency and lower GHG emissions.
Siting and land use	Screwed into vehicles' engine cylinder heads
Design (components) and Operation	An electrically operated and electronically controlled direct injection system comprises three basic components: 1) high pressure fuel pump; 2) fuel pressure sensor; and 3) injectors; operationally controlled by a vehicle's engine control unit (ECU); an onboard micro-computer that directs various sub-systems of the vehicle by actuating certain key components and monitoring engine performance through feedback from multiple sensors. A high pressure fuel pump lifts fuel from a vehicle's fuel tank to injectors mounted on an onboard engine. Externally, a high pressure fuel pump has a fuel inlet and high pressure fuel outlet. Most pumps in this category are single piston pumps mechanically-driven by the host vehicle's camshaft. As a pump's plunger retreats, the primary electric pump fills up the chamber with fuel at about 3 to 5 bars. On the forward movement of the plunger, fuel is pressurised well beyond 100 bars. An internal pressure control solenoid sets a limit to the maximum operating pressure and returns excess fuel to the pump intake, when engine demand is relatively low. A high pressure fuel outlet transports fuel at a controlled flow rate and pressure to the fuel rail. A high pressure fuel sensor fitted to the fuel rail monitors fuel pressure and continually sends a modulated signal to the ECU which actuates the high pressure pump solenoid as required to adjust pressure of fuel pumped to the rail (Fiengo et al., 2013; Çelik and Ozdalyan, 2010). A pressure regulation electro-valve on the fuel rail returns excess fuel to the tank. Under its own pressure, fuel flows into the chamber and nozzle of a solenoid-operated fuel injector, but remains sealed off from associated engine cylinder by a pressure valve. Fuel injection occurs when the when the solenoid winding is activated by a trigger

[88] gasoline (in the US)

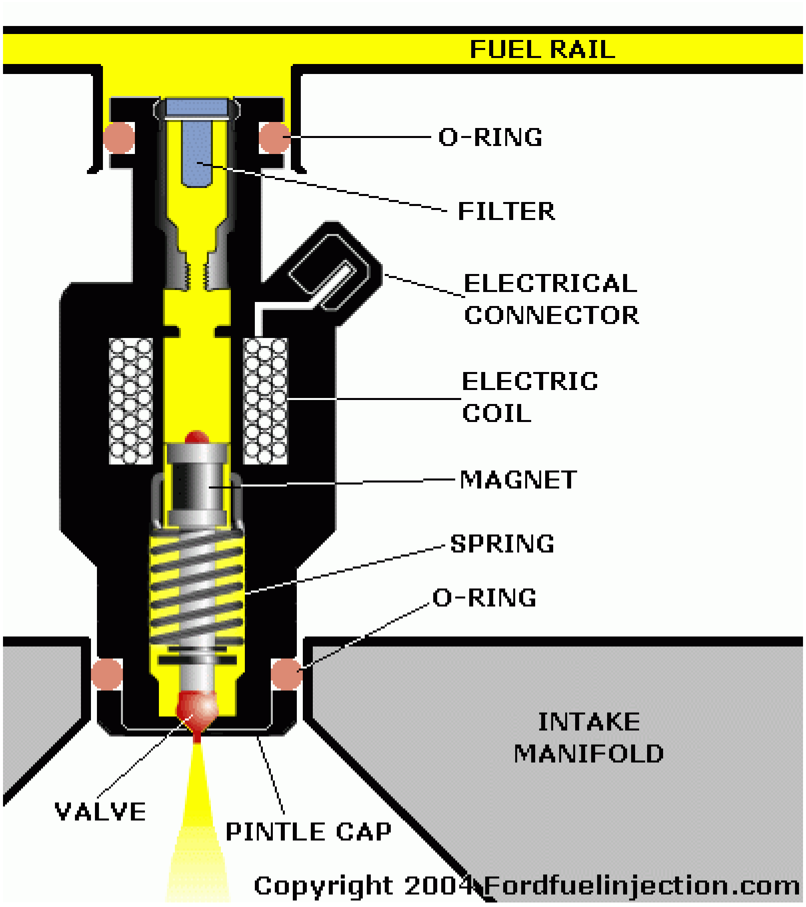
	current from the ECU thus generating a magnetic field that lifts the injector pintle off its seat releasing an atomized jet of fuel droplets with a Sauter mean diameter (SMD)[89] no larger than 20 microns in a 10 to 15 degree spray angle from the injector nozzle. Pulse of fuel injected into the combustion chamber generally lasts between 0.4 and 5 microseconds, and end when the injector's solenoid winding is de-energised and the pintle returns to its rest position. An O-ring on nozzle tip prevents gases leaking out of the cylinder and the nozzle's plastic tip insulates injector from heating. Additional to the customary fuel filter that removes gross-sized impurities from fuel stream, the injector incorporates a filter to trap microscopic-sized fuel contaminants Fiengo et al., 2013; Çelik and Ozdalyan, 2010; Alkidas, 2007, Zhao et al., 1999)
Cost	In new vehicles, the cost of direct injection systems is inseparable from the vehicle cost which itself is strongly correlated to performance-related specifications such as volumetric displacement, top speed, range, acceleration, tailpipe emissions, and brand name as well. Thus, indicative costs of a 1,300 and 1,600cc vehicles fitted with direct injection technology lies between 19,000 and 22,000 Euros, with corresponding powertrain specific costs of 50.9 and 67.3 Euro/kW (Thiel et al, 2010). Assuming, a retrofit strategy is adopted by policy-makers/owners, the cost of direct injection unit approximates the market price of key component parts, cost of engine modifications and professional fees of engineer carrying out retrofit. At this point, a conservative estimate of direct injection retrofit cost falls within the range 1,300 to 1,550 Euros.
Supporting infrastructure	High quality roads
Advantages	GDI fuel mixing strategy gives better volumetric efficiency, fuel economy, engine power compared with port fuel injected and carburetted engines (Fiengo et al., 2013; Zhao et al., 1999) About 35% greater fuel economy than carburetted engines (Kobayashi et al., 2009) Power and torque higher than PFI engines by 20% and 35% (Çelik and Ozdalyan, 2010) Lower exhaust emissions (Çelik and Ozdalyan, 2010)
Disadvantages /Challenges	Can slightly increase unburnt hydrocarbons in emissions at idle and partial engine loads (Çelik and Ozdalyan, 2010; Zhao et al., 1999) Causes relative increase in NO_X emissions compared to carbureted engines
Abatement potential	Greenhouse emissions reduction attributable to GDI engine fuel economy (Fiengo et al., 2013; Sullivan et al., 2004; Zhao et al., 1999) is mediated by a complex function of engine make, fuel type, fuel quality vehicle loads and driving patterns. CO_2 emissions reductions derived from literature range between 40 and 75gCO_2/km (Sullivan et al., 2004; Zhao et al. 1999). In cars operating on a GDI engine and low-sulfur fuel, emissions of oxides of nitrogen (NO_x) are lower by 40% but weighted-average emissions total hydrocarbon emissions linked to in-cylinder wetting are significantly 3 to 10 times higher than those from a PFI vehicle (Li et al., 2000; Cole et al., 1998).
Level of penetration	Less than 40% of national vehicle fleet estimated to be running on diesel compression ignition engines.

[89] The SMD is defined as the diameter of the droplet having the same surface to volume ratio as that of the overall spray (Fiengo et al., 2013)

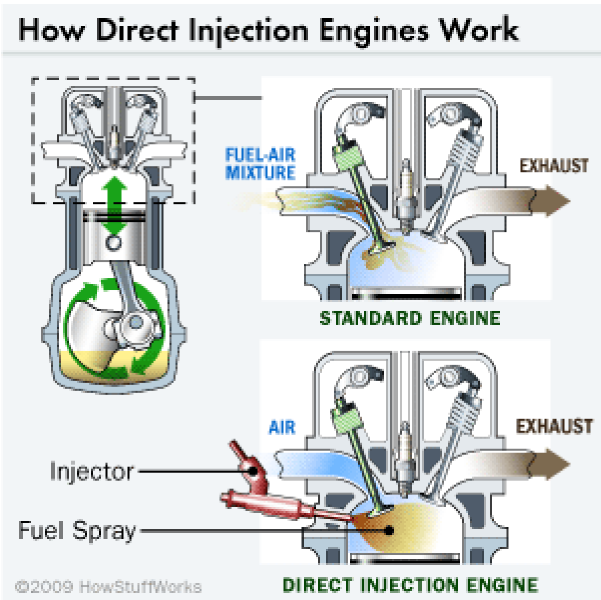


Source: https://www.hitachi-automotive.us/images/Products/OEMproducts/products_ems_01_photo02.jpg

Source:
http://www.autodiagnosticsandpublishing.com/feature/fuel-injector-testing_files/Fuel%20Injector.jpg



Source: http://www.protowrxs.com/OldFuelInjection/Images/injector02.gif



Source: http://s.hswstatic.com/gif/direct-injection-engine-2.gif

Further Reading

Alkidas, A.C., 2007. Combustion advancements in gasoline engines. Energy Conversion and Management 48, 2751–2761

Çelik, M.B., Ozdalyan, B., 2010. Gasoline Direct Injection, Fuel Injection, Daniela Siano (Ed.), ISBN: 978-953-307-116-9, InTech.
Available from: http://www.intechopen.com/books/fuelinjection/gasoline-direct-injection

Cole, R., Poola, R., and Sekar, R., "Exhaust Emissions of a Vehicle with a Gasoline Direct-Injection Engine," SAE Technical Paper 982605, 1998, doi:10.4271/982605.

Fiengo, G., Gaeta, A., Palladino, A., Giglio, V., 2013. Basic Concepts on GDI Systems in Common Rail System for GDI Engines: Modelling, Identification and Control, pp 17 -33. Springer Briefs in Electrical and Computer Engineering. DOI: 10.1007/978-1-4471-4468-7_2.

Kobayashi S., Plotkin, S. Ribeiro, S.K., 2009. Energy efficiency technologies for road vehicles. Energy Efficiency 2:125–137. DOI 10.1007/s12053-008-9037-3

Li, J. Huang, Y., Alger, T.F., Matthews, R.D., Hall, M.J., Stanglmaier, R.H., Roberts, C.E., Dai, W., Anderson, R.W., 2000. Liquid Fuel Impingement on In-Cylinder Surfaces as a Source of Hydrocarbon Emissions From Direct Injection Gasoline Engines**.** *J. Eng. Gas Turbines Power* 123(3), 659-668. doi:10.1115/1.1370398

Sullivan, J.L., Baker, R.E., Boyer, B.A., Hammerle, R.H., Kenny, T.E., Muniz, L., Waalington, T.J., 2004. CO_2 Emission Benefit of Diesel (versus Gasoline) Powered Vehicles. Environmental Science & Technology. Vol, 38, No. 12, 3217-3223

Thiel, C., Perujo, A., Mercier, A. 2010. Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. Energy Policy 38, 7142–7151.

Zhao, F., Lai, M.C., Harrington, D.L., 1999. Automotive spark-ignited direct-injection gasoline engines. Progress in Energy and Combustion Science 25 (1999) 437–562

Websites

https://en.wikipedia.org/wiki/Internal_combustion_engine
https://www.howacarworks.com/basics/how-a-fuel-injection-system-works
https://en.wikipedia.org/wiki/Engine_control_unit