Gasoline Direct Injection

Gasoline direct injection (DI) engines have been lurking in the shadows of gasoline-burning, internal combustion engine development for decades but are now becoming mainstream. This is all good, as DI engines can be tuned to unruly power levels while still exhibiting pleasant street manners and good mileage. But how does it work, and why is it good? This story is here to answer those questions.

DI?
The main aspect that defines a DI engine is the application of the fuel directly into the combustion chamber. Currently, most production gas engines use port fuel injection, where fuel is applied in the intake ports upstream of the intake valve. Port fuel injection and DI are implemented with electronic fuel injectors and an engine computer telling the injectors when to open and close to allow pressurized fuel to pass into the engine. But port fuel injection is less precise since it just sprays fuel into the intake port, which then mixes with the air in the port and rushes into the combustion chamber when the intake valve opens. The DI fuel application is a big leap forward. It allows precise timing of when fuel enters the combustion chamber and opens up a plethora of opportunities for engine tuners to make power, reduce emissions, and increase the durability of the engines—all at the same time.

Timing Is Everything
This adjustability in when the fuel is added to the cylinder is the holy grail of power production. Designers of early carbureted/distributor ignition and port fuel-injected/distributor engines only had one tuning variable that could be adjusted dynamically based on engine rpm and load: ignition timing (with counterweights on the distributor and a vacuum line from the intake manifold, respectively). Later port fuel-injected engines were developed with camshafts that could be phased (advanced or retarded) 20 or so degrees based on rpm and load. Now, DI allows the fuel application timing to be added to the cam phasing and ignition timing as another dynamic tuning tool. The DI fuel application is defined by two categories: fuel apply rate and fuel timing.

Fuel Apply Rate
The fuel apply rate is tuned via the pressure in the common fuel rail that the fuel injectors are connected to, the number of times the injector is opened to allow fuel to pass through it (during the intake cycle), and the duration of those openings. DI fuel systems are substantial in their design because they
usually generate and hold fuel pressurized at a whopping 2,200 psi or more (the DI fuel rail tube often has about a 1/8-inch wall thickness to handle these extreme pressures) rather than the 40 to 60 psi common in port injection. These extremely high pressures allow the injector to flow enough fuel to achieve stoichiometric combustion (the desired 14:1 ratio of fuel and air) in a little less than half the number of degrees of crank rotation as compared with a port fuel injection engine.

Here is the explanation of that statement: The injectors on a port fuel injection engine can flow fuel for almost the entire 720 degrees of crank rotation (at lower rpm they close occasionally, but at higher rpm they can be open for as long as 720 degrees). This is acceptable as the fuel/air mixture filling the intake ports only flows into the combustion chambers when the intake valve is open.

On a DI engine, the fuel injector usually applies fuel into the combustion chamber after the exhaust valve has closed (to avoid the fuel just spraying out the exhaust port) and before the spark plug fires-usually a crank rotation of about 310 degrees. Having less than half the crank rotation to get all the fuel in the chamber means the pressure pushing the fuel needs to be much higher, thus the 2,200 psi. The fuel injectors on a DI engine often open and close more than once during the intake stroke to provide enough fuel for combustion while applying it at the ideal time.

**Fuel Timing**

Probably the most exciting feature of the modern DI system is the ability to time (in crank rotation degrees) when the fuel apply is made in the combustion chamber. On a production vehicle program, this is a dream from heaven for the engine calibrators, as they are faced with very demanding but specialized situations such as the need to get the catalytic converter up to temperature in the first few seconds of start-up to minimize emissions. This important situation is ably handled by the engine calibrator programming the exhaust valve to be held open longer than usual (increasing valve overlap), retarding the ignition, and using a lean fuel apply-all to light a majority of the combustion in the exhaust pipe.

Even more cool is that in the instant before this moment-at engine cranking-the engine calibrator is able to set the fuel apply to full rich (a longer-duration fuel apply) with a little less retarded timing and very little valve overlap. This sprays fuel when the piston is coming up the bore, rebounding fuel off the piston (which is why the piston has that weird bowl on its top), and directly hitting the spark plug electrode. See what we mean? The number of combinations is insane, but the opportunity to give the engine
exactly what it wants/needs to maximize efficiency and power production at any combination of rpm and load is all there with DI.

**Downsides**
So far, this probably all sounds good and you're wondering why DI hasn't been on the streets for decades. The simple answer is the technology wasn't ready for prime time. The hardware to do DI, like the injectors, fuel pumps, and so on, is similar to what diesel engines were using years ago, but the engine control computers and software used to manage all these variables wasn't up to the job for production automobile applications (which are essentially space shuttles built for the Three Stooges to drive). These components caught up to the need a few years ago, which is why you are seeing DI engines more and more today. But beware. The immense capability of DI comes with a staggering amount of complexity. The aftermarket and enthusiast segments will undoubtably figure it out, but the industry should be compared to what it was like in 1985 with regard to port fuel injection-no aftermarket injectors, pumps, controls, experience, and so on. But mark our words: That will change once the power potential is experienced by a few key players.

<table>
<thead>
<tr>
<th>Differences Between Gasoline Direct Injection And Traditional Port Fuel Injection</th>
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<tbody>
<tr>
<td>Where fuel is applied</td>
<td>DI</td>
<td>Port Fuel Injection</td>
</tr>
<tr>
<td>Combustion chamber</td>
<td>Intake port</td>
<td></td>
</tr>
<tr>
<td>Fuel rail pressure</td>
<td>2,200 psi</td>
<td>Approximately 60 psi</td>
</tr>
<tr>
<td>Fuel apply (crank degrees)</td>
<td>Approximately 310 degrees</td>
<td>Up to 720 degrees</td>
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<tr>
<td>Ignition</td>
<td>Spark plug-based</td>
<td>Spark plug-based</td>
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<tr>
<td>Compression ratio</td>
<td>Higher by approximately 10 percent</td>
<td>Limited by fuel application</td>
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<tr>
<td>Cam phasing</td>
<td>Mandatory</td>
<td>Recommended</td>
</tr>
<tr>
<td>Intake air/fuel temperature</td>
<td>Lower from vaporizing fuel</td>
<td>Limited by fuel application</td>
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DI Likes Boost
The DI applications that hold the most potential from an enthusiast's perspective are turbocharging and supercharging. The precise tuning of the fuel apply and timing really allows the calibrator to get creative. One example of the power potential is in low-rpm- to high-rpm-acceleration runs under high load. With a DI engine package, the common way to make power is similar to what turbo drag racers do at the starting line to get their turbos spinning fast and making boost.

At acceleration, the DI engine calibration is set to add exhaust/intake valve overlap. This allows a small amount of the intake boost to pass directly through the combustion chamber and spin up the turbo. Also, the fuel apply and timing are retarded to minimize the fuel or combustion gases going out the exhaust pipe (but still maintain stoichiometric air/fuel ratio). This is similar to how a drag car with a big turbo and electronic fuel injection launches. The engine calibration is set on a two-step program to limit the spark to a few cylinders every rotation, and the ignition is retarded the max amount. This puts the explosive combustion event in the exhaust pipe and helps to quickly get the turbo spinning at max speed. Both methods get the turbo spinning, but the drag racing situation is hellaciously violent (they pop and bang really loudly), while the DI situation quietly provides torque that sets you back in your seat—from an engine that is about 2 liters in size.

Probably the coolest aspect of the DI system is that this is just one example—it can be tuned to any thousands of situations to maximize power output. And for those reasons, DI is going to become the next big thing in the performance world.

Domestic Cars With DI Engines
'09 to '10 Buick LaCrosse and Enclave
'10 Cadillac STS and CTS
'10 Chevrolet Camaro V-6
'10 Chevrolet HHR SS
'10 Chevrolet Traverse
'10 GMC Acadia
'07 to '10 Pontiac Solstice GXP
'07 to '10 Saturn Sky Red Line

LNF Stage kit install
There is a stage kit available from GM Performance Parts (PN 19212670) for the Chevrolet HHR SS, Cobalt SS, Solstice GXP, and Sky Red Line (all are powered by the impressive 2.0L turbo engine, regular production order LNF,
which is why enthusiasts call it the LNF engine) that produces a truly surprising power increase. The kit locks calibration in for premium fuel use and runs slightly higher boost in certain situations. The kit consists of only two manifold air pressure sensors (and new pigtail connectors) and a new calibration and nets more than 85 lb-ft and 20 hp.