Introduction

- Engine Designers have sought to improve engine efficiency in an endeavor to meet growing environmental demands, such as those for energy conservation and the reduction of CO₂ emission to limit the negative impact of the green-house effect.

- Demand for design and build ever more efficient engines has led to development of gasoline direct injection engine. For years, automotive engineers have believed this type of engine has the greatest potential to optimize fuel supply and combustion, which in turn can deliver better performance and lower fuel consumption.

- Presently an in-cylinder direct injection engine for use on production vehicles has been designed and this advanced Gasoline Direct Injection GDI engine is the realization of engineering dream.
GDI: An Engineering Dream

- For years, engineers have known that if they could build a petrol engine that worked like a diesel engine—in other words, one in which fuel is injected directly into the cylinder and the stratified, rich mixture right near the spark plug is ignited—they would have an engine that achieved both the fuel efficiency of a diesel engine and attained the high output of a conventional petrol engine.

- Development of such an engine has been impeded by petrol's poor combustibility.

GDI: An Engineering Dream

- Diesel engines operate on a thermodynamic cycle, meaning that as long as a sufficient temperature is reached, thorough ignition will occur regardless of the air/fuel mixture condition.

- In order to achieve combustion with petrol, gaseous fuel and air must be mixed to form just the right air/fuel mixture, and precise control of position and timing of the air/fuel mixture is necessary to ensure delivery of this mixture to the very limited space between the spark plug electrodes in the very specific timing of ignition.

- The GDI engine is able to achieve this through Mitsubishi’s technology that enables precise control over the air/fuel mixture.
Environmental Issues

- Global issues, and
- Local issues mainly centering on urban areas

- The reduction of the greenhouse gas, CO₂, is the most important issue when considering the environment from a global perspective.
- The combustion of an engine that uses Hydrocarbons as fuel is a process in which fuel is converted to CO₂. A viable solution to reducing the amount of CO₂ emissions is by improving the efficiency of vehicles and reducing the amount of fuel they consume.

- In order to preserve the local environment of urban areas, it is important to reduce the level of HC and NOx released by cars.

Reducing CO₂ Emissions

The Advantages of GDI Technology in Reducing CO₂ Emissions

- Lowering CO₂ emissions demands a global outlook. Accordingly, we must focus on reducing emissions, starting from the production stage, through to the end of a vehicle's life cycle.
- Some technologies, while enabling major CO₂ emission reductions during combustion, involve higher-than-usual output during production or recycling, resulting in an increase in total emissions over the life of the vehicle.
- The GDI engine doesn't necessitate major alterations to existing production processes, production stage CO₂ emissions are fundamentally the same as for conventional petrol engines.
- Moreover, with the GDI engine, CO₂ emissions at the recycling stage are on a par with those of conventional petrol engines. Any reduction in on-road fuel requirements will thus translate directly into a reduction in total CO₂ output.
Reducing CO₂ Emissions
The Advantages of GDI Technology in Reducing CO₂ Emissions

Steps in Reducing CO₂
Reducing Carbon Monoxide (CO), Hydrocarbon HC and NOx Emissions

- Mitsubishi Motors has continued to conduct research and development in technology for cleaner exhaust emissions.

- Particular focus has been on the development of new technical features that will reduce the NOx and HC emission levels by more than 80% without impairing the GDI engine's efficiency.

- These new technical features include: an earlier activation of the catalyst by Two-Stage Combustion, a feature made possible from the GDI's precise control over the formation of the air/fuel mixture; a reactive-type exhaust manifold, which maximises this effect and; exhaust gas recirculation (EGR), and a revamped, lean NOx catalyst.

- These features will be integrated in the most effective, practical manner possible, ensuring the GDI engine continues to comply with environmental requirements world-wide.
Vehicles Take Offs

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<th>Years</th>
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<th>2010</th>
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<td>GDI equipped vehicles</td>
<td></td>
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<tr>
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Major Objectives of the GDI engine

- Ultra-low fuel consumption than that of even diesel engines
- Superior power to conventional MPFI engines
Difference Between MPFI and GDI

- In a MPFI or Multi-Point Fuel Injection engine, the fuel is injected in each intake port. It is currently one of the most widely used systems. However, even in MPFI engines there are limits to fuel supply response and the combustion control because the fuel mixes with air before entering the cylinder.

- In a GDI engine, gasoline is directly injected into the cylinder as in a diesel engine, and the injection timings are precisely controlled to match load conditions.

Outstanding Characteristics of GDI Engine

- Extremely precise control of fuel supply to achieve fuel efficiency that exceeds that of diesel engines by enabling combustion of an ultra-lean mixture supply.

- Very efficient intake and relatively high compression ratio unique to the GDI engine deliver both high performance and response that surpasses those of conventional MPFI engines.
Progress Towards Higher Efficiency and Power

Transition of Fuel Supply Systems
GDI and MPFI Engines
Key Technical Features

- Upright straight intake ports for optimal airflow control in the cylinder

Conventional petrol engines use horizontal intake ports. The GDI engine is the first engine ever to feature upright, straight intake ports. This enables them to direct a greater volume of air smoothly and directly down to the piston.

Key Technical Features

- Curved-top pistons for better combustion

Contributes to more effective combustion by shaping the air charge into a compact, concentrated reverse vertical tumble flow and concentrating the injected fuel immediately beneath the spark plug.
Key Technical Features

- High pressure fuel pump to feed pressurized fuel into the injectors

The high-pressure fuel pump delivers petrol at an appropriately high pressure to permit injection directly into the cylinder.

Key Technical Features

- High-pressure swirl injectors for optimum air-fuel mixture

The high-pressure swirl injector controls the vaporisation and dispersion of the fuel spray, adjusting the spray pattern as necessary to match each of the GDI engine's combustion modes.
Key Technical Features

- Vertical Tumble Flow

The GDI engine's curved-top piston shapes the air drawn into the cylinder into a compact vertical tumble flow, which is maintained throughout the compression stroke. This tumble flow is particularly effective because it carries the air up to the spark plug in a concentrated form, ensuring a rich mixture at the spark plug, even when the air/fuel ratio is lean, resulting in clean, thorough combustion.

Challenged to the Vehicle Manufacturers

- Offer vehicles that deliver excellent fuel efficiency
- Superb vehicle performance
- Maintaining cleaner emissions
- Driving comfort.

Growing awareness of global warming as a big threat to the environment, has added yet another dimension to this challenge.

In order to prevent global warming, the reduction of CO2 is called for.

There is an immediate need to develop and promote widely the use of an automotive power plant that emits significantly less CO2 than conventional petrol engines.
New Technical Features of GDI

- An earlier activation of the catalyst by Two-Stage Combustion. A feature made possible by the GDI's precise control over the formation of the air/fuel mixture,
- A reactive-type exhaust manifold, which maximises this effect and;
- Exhaust gas recirculation (EGR), which takes advantage of the engine's highly stable combustion; and
- A revamped, lean NOx catalyst.

By combining these features in a highly streamlined format that reflects global market trends, an improved GDI engine will meet global environmental requirements.

Key Concepts

(1) Two Combustion Modes

- In response to driving conditions, the GDI engine changes the timing of the fuel spray injection, alternating between two distinctive combustion modes
  - stratified charge (Ultra-Lean combustion), and
  - homogenous charge (Superior Output combustion).

- Under normal driving conditions, when speed is stable, the GDI engine operates in Ultra-Lean Mode. A spray of fuel is injected over the piston crown during the latter stages of the compression stroke, resulting in a optimally stratified air/fuel mixture immediately beneath the spark plug. This mode thus facilitates lean combustion and fuel efficiency comparable to a diesel engine.

- The GDI engine switches to Superior Output Mode when the driver accelerates, indicating a need for greater power. Fuel is injected into the cylinder during the piston's intake stroke, where it mixes with air to form a homogenous mixture. The homogenous mixture is similar to that of a conventional MPI engine, but by utilising the unique features of the GDI, an even higher level of power than conventional petrol engines can be achieved.
Key Concepts
(1) Two Combustion Modes

- Partial Load
  - Compression stroke injection
  - Stratified air/fuel mixture
  - Ultra-lean combustion

- High Load
  - Intake stroke injection
  - Homogenous mixture
  - Stoichiometric combustion

The GDI engine's ability to precisely control the mixing of the air and fuel is due to a new concept called wide spacing, whereby injection of the fuel spray occurs further away from the spark plug than in a conventional petrol engine, creating a wide space that enables optimum mixing of gaseous fuel and air.

In stratified combustion (Ultra-Lean Mode), fuel is injected towards the curved top of the piston crown rather than towards the spark plug, during the latter stage of the compression stroke. The movement of the fuel spray, the piston head's deflection of the spray and the flow of air within the cylinder cause the spray to vaporize and disperse. The resulting mixture of gaseous fuel and air is then carried up to the spark plug for ignition.

The biggest advantage of this system is that it enables precise control over the air-to-fuel ratio at the spark plug at the point of ignition.
Key Concepts

(2) Precise Control Over the Air/Fuel Mixture

- Fuel spray impingement and vapourisation.
- Fuel spray is carried up to spark plug.
Key Concepts
(3) Better Fuel Efficiency

- The concept of wide spacing makes it possible to achieve a stratified mixture, enabling the GDI engine to offer stable, ultra-lean combustion, allowing a significant improvement in fuel efficiency.

- In addition to ultra-lean combustion, the GDI engine achieves a higher compression ratio because of its anti-knocking characteristic and precise control of injection timing.

- These features contribute to a drastically lower fuel consumption.

- The GDI engine improves fuel economy by 33% in the Japanese 10-15 mode driving cycle which represents typical urban driving conditions.
Key Concepts
(4) Improved Power

- In high-load operation, charge burns in a homogenous mixture mode, the GDI engine functions like any other MPI engine. Hence the GDI engine achieves substantially higher power than a conventional engine.

- Fine spray of fuel is injected in a wide shower directly into the cylinder, where it vaporizes instantly into the air flow. This causes the air to cool and contract, allowing additional air to be drawn in and improving volumetric efficiency. The cooling of the intake air prevents knocking, and results in higher power output.

Key Concepts
(4) Improved Power

- The GDI engine's prevents knocks. With conventional MPI engines, strong knocking occurs during acceleration. This is caused by petrol adhering to the intake ports.

- With the GDI engine, fuel is injected directly into the cylinder and burned completely, meaning that transient knocking is suppressed. This in turn, allows higher output in the early stages of acceleration, when power is most needed.

- Mitsubishi has achieved precise control over formation of the air/fuel mixture. They capitalized on this achievement to develop an innovative anti-knock technology called Two-Stage Mixing.

- In high load, a homogenous air/fuel mix is used to prevent partially dense mixtures that cause soot to form. In contrast, the new Two-Stage Mixing technology prevents soot even during stratified mix, when a dense mixture forms. This is how knocking can be prevented.
Key Concepts
(4) Improved Power

- In Two-Stage Mixing, about 1/4 of the total volume of fuel is injected during the intake stroke. This forms an ultra-lean fuel mixture which is too lean to burn under normal conditions.

- The remaining fuel is injected during the latter stages of the compression stroke. The key is that the air/fuel mixture is divided into a very lean air/fuel mixture and a rich air/fuel mixture. Knocking occurs most frequently in a stoichiometric mixture, but is less likely to occur when the mixture becomes leaner or richer. Because the rich mixture is formed immediately before ignition, there is no time for the chemical reaction that causes knocking to take place. This is another of the factors that prevent knocking.
Key Concepts

(4) Improved Power

- The emission of soot is prevented, even when a dense air/fuel mixture is formed, and excess air is not sufficient. If air were the only gas present in the combustion chamber—as is the case with an ordinary diesel engine—the enriched charge would cool, causing soot to form.

- With Two-Stage Mixing, the enriched charge, created in the part of the chamber where the dense air/fuel mixture exists, shifts toward the other side of the chamber, where the mixture is leaner, as it burns. At this point, the enriched charge causes the ultra-lean mixture, which is too lean to burn under ordinary circumstances, to ignite. The combustion of the ultra-lean mixture, in turn, causes the enriched charge to re-ignite. It is this process that suppresses the formation of soot.

- This is the first time in the long history of petrol engines that direct control of combustion has been used to suppress knocking, and it further underscores the importance of achieving precise control over the air/fuel mixture.
Key Concepts

- The chart compares the GDI engine's total power output with that of a conventional MPI engine. With the GDI engine, the effect of Two-Stage Mixing and suppressed transient knocking boosts the low-speed range torque necessary for acceleration. Moreover, the cooling effect of intake air and the smoothness with which it is drawn in through the upright straight intake ports enable greater power at medium and high-speed ranges.

![Chart comparing GDI and MPI engines](image)

How GDI Engine Meets Emission Standards

New technical features include:

- **Two-Stage Combustion**, GDI's precise control over the formation of the air/fuel mixture,
- A reactive-type exhaust manifold, which maximises this effect and;
- exhaust gas recirculation (EGR), and
- A revamped Lean NOx catalyst

![Diagram of GDI engine components](image)
Reducing HC Emissions

- In petrol engines, a highly effective Three-way catalyst is used to remove HC from exhaust emissions. The catalyst activates at temperatures above 250. It is necessary to warm up the catalyst immediately after the engine is started.

- This is made possible by Two-Stage Combustion, and a Reactive-type exhaust manifold, which increases the effectiveness of the process.

- The GDI engine operates in Stratified Combustion Mode when it is idling immediately after being started.

- Fuel is injected during the compression stroke, ensuring very lean operation.

- Combustion occurs toward the end of the compression stroke and concludes at the beginning of expansion, by which time the gases in the engine have risen to a high temperature.

- At this point, when fuel is injected again towards the end of expansion.

- The fuel injected into high-temperature atmospheric gas ignites, and the temperature of the operational gas rises, causing the mixture to ignite and burn a second time. As a consequence, the temperature of the gases rises as high as 800, compared to about 200 in the case of idling immediately after engine start-up.
Earlier Activation of Catalyst

- Without Two-Stage Combustion, the catalyst takes more than 100 seconds to warm up to 250.

- With Two-Stage Combustion, however, warm-up time is cut in half.

- The use of a Reactive-type exhaust manifold, which retains exhaust gases and mixes them with air to ensure that the combustion response reaction which was started in the combustion chamber continues inside the manifold, reduces the warm-up time to a mere 20 seconds.

- As a result, the HC emission level immediately after engine start-up can be reduced drastically.
2. Reducing NOx Emissions
   (1) EGR (Exhaust-gas recirculation)

- In order to reduce the level of NOx emissions, EGR is employed to recycle a large volume of exhaust back into the engine.

- Although EGR has long been known to permit the reduction of NOx emissions, its use in conventional petrol engines has been limited by the fact that it hinders combustion.

- With the GDI engine, the high density of the air/fuel mixture in the combustion area makes it possible to utilize high-volume EGR without endangering combustion stability. As a result, the GDI engine reduces NOx levels in emissions utilizing EGR of up to 70%.
2. Reducing NOx Emissions
   (2) Lean NOx Catalytic Converter

- EGR is conducted to reduce the level of NOx emitted in the engine's exhaust. The greater the load on the engine, the lower the volume of EGR utilized.

- Lean NOx catalytic converter that facilitates elimination of NOx even from lean-mixture emissions.

- Lean NOx catalytic converters currently come in two varieties:
  - The Selective Reduction Type, and
  - The NOx Trap Type.

- The latter have been proven highly effective when new, but their viability is considerably reduced when petrol with a high sulfur content is used.

- In contrast, Selective Reduction Type NOx catalysts are less effective in the early stages, are hardly damaged by sulfur.

- Mitsubishi Motors have decided to offer the appropriate type of Lean NOx catalyst with the GDI engine, depending on the sulfur content of the region in which the engine will be used.
Thank you