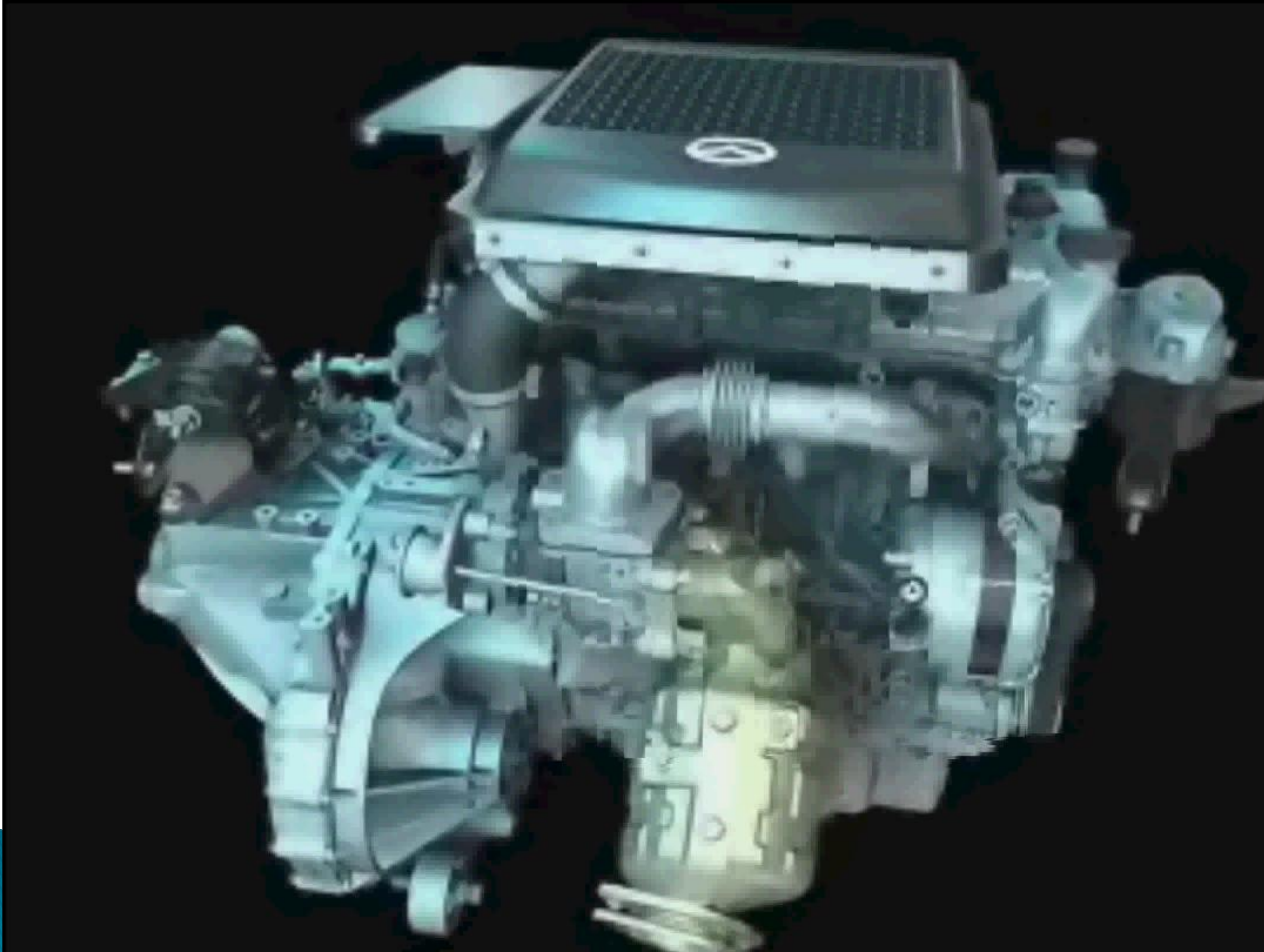

An Overview of Gasoline Direct Injection

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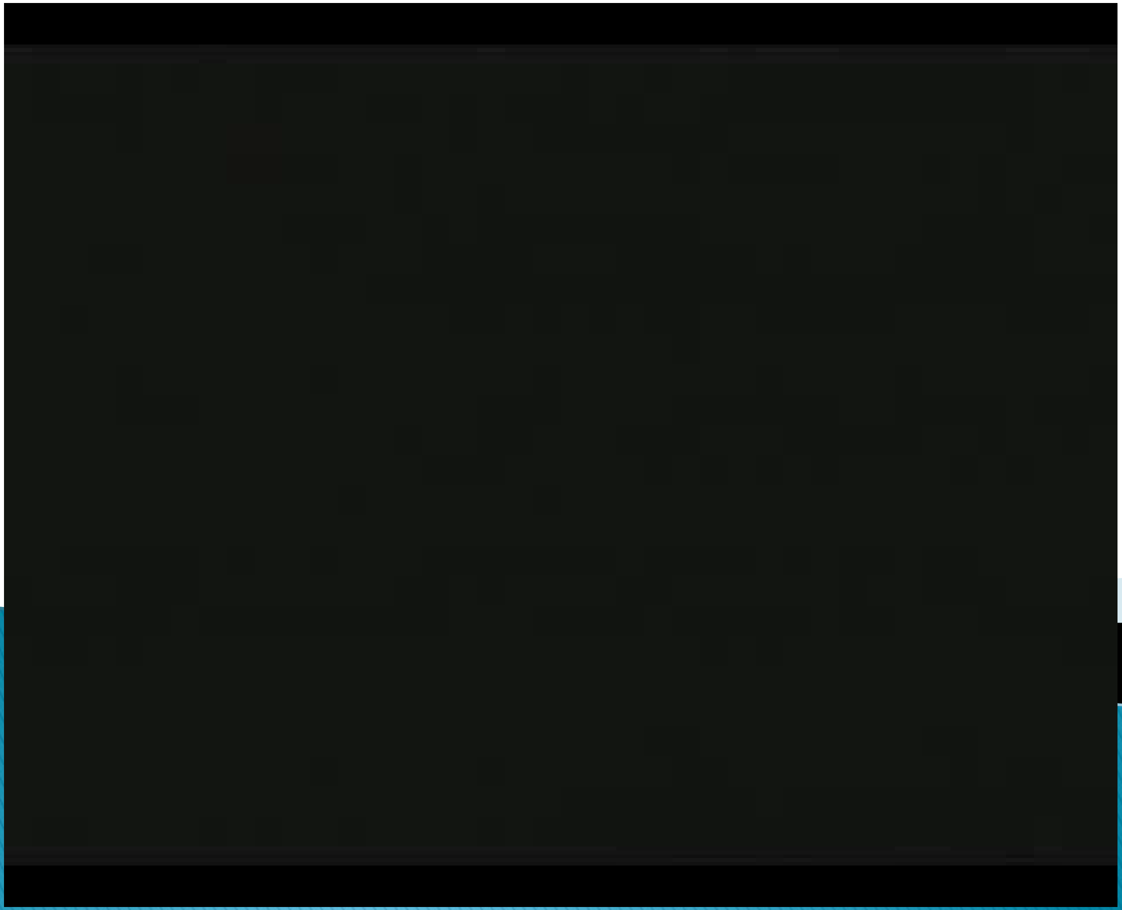
Gasoline Direct Injection

Changing "The Rules"



Why GDI?

- **Fuel is injected under high pressure directly into the combustion chamber.**
  - Allows the precise control of charge stratification vital to ignite ultra-lean air / fuel mixtures.
- **Direct injection has less need for a Throttle.**
  - Eliminates pumping loss associated with drawing air around a conventional engine's butterfly valve.

GDI vs PFI

- PFI
  - 2875 Measurements for Calibration.
  - Lambda Closed-Loop Control.
  - TWC and Rich/Lean Cycle.

- GDI
  - 12,000,000 Measurements. (Engine Mapping)
  - 40% More Computer Functions.
  - High Pressure Pump, Injectors, Valves, and Fuel Rail.
  - High Pressure & Exhaust Temperature Sensors
  - NOx Storage Catalyst

GDI Advantage & Disadvantage

- Advantages
  - 25% Improvement in Fuel Economy
  - 12- 15% Reduction in Emissions
  - Higher Compression

- Disadvantages
  - High Cost
  - More Components
  - NOx Storage Catalyst Required.
  - Complex Strategies.
  - Possibly Six Operating Modes.

Compression Ratios

- Higher Compression
- Turbo Charging
- Knock?
  - Gas Injected Just Before Ignition.
  - Less Time for Knock.
  - Colder Fuel at Ignition.
  - Tighter Controls.
  - Higher Compression Ratios and Boost Pressures.
  - Better MPG and Higher HP.

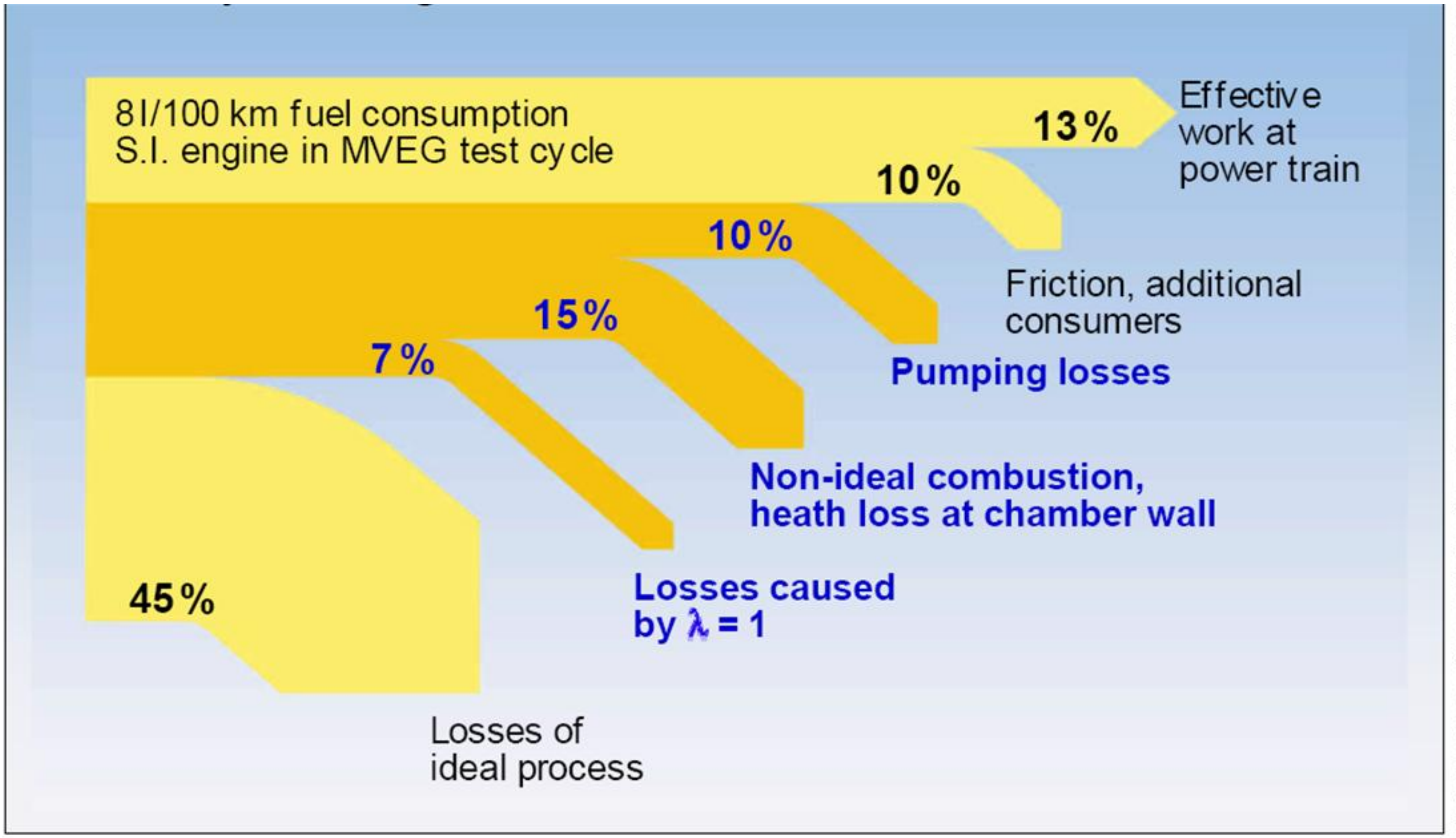
General Specifications

- **Fuel Pressure** = 500-2900 psi. (high side)
- **Injector Opening Voltage** = 50- 90V Capacitor Kick
- **Injector ON time** = As little as 400µs. @ Idle
- **Transfer Fuel Pressure** = 50-60 psi.

Terminology

- Stratified
  - Fuel/Air Mixture is Rich around Spark Plug Only, Remaining Mixture in Cylinder is Lean.
- Stratified Cold Start
  - Retarded Ignition Timing, Increases Exhaust Temp, Faster Catalyst Warm-up.
- Homogeneous
  - Air and Fuel are Equally Mixed in Cylinder.

SI Engine Efficiency

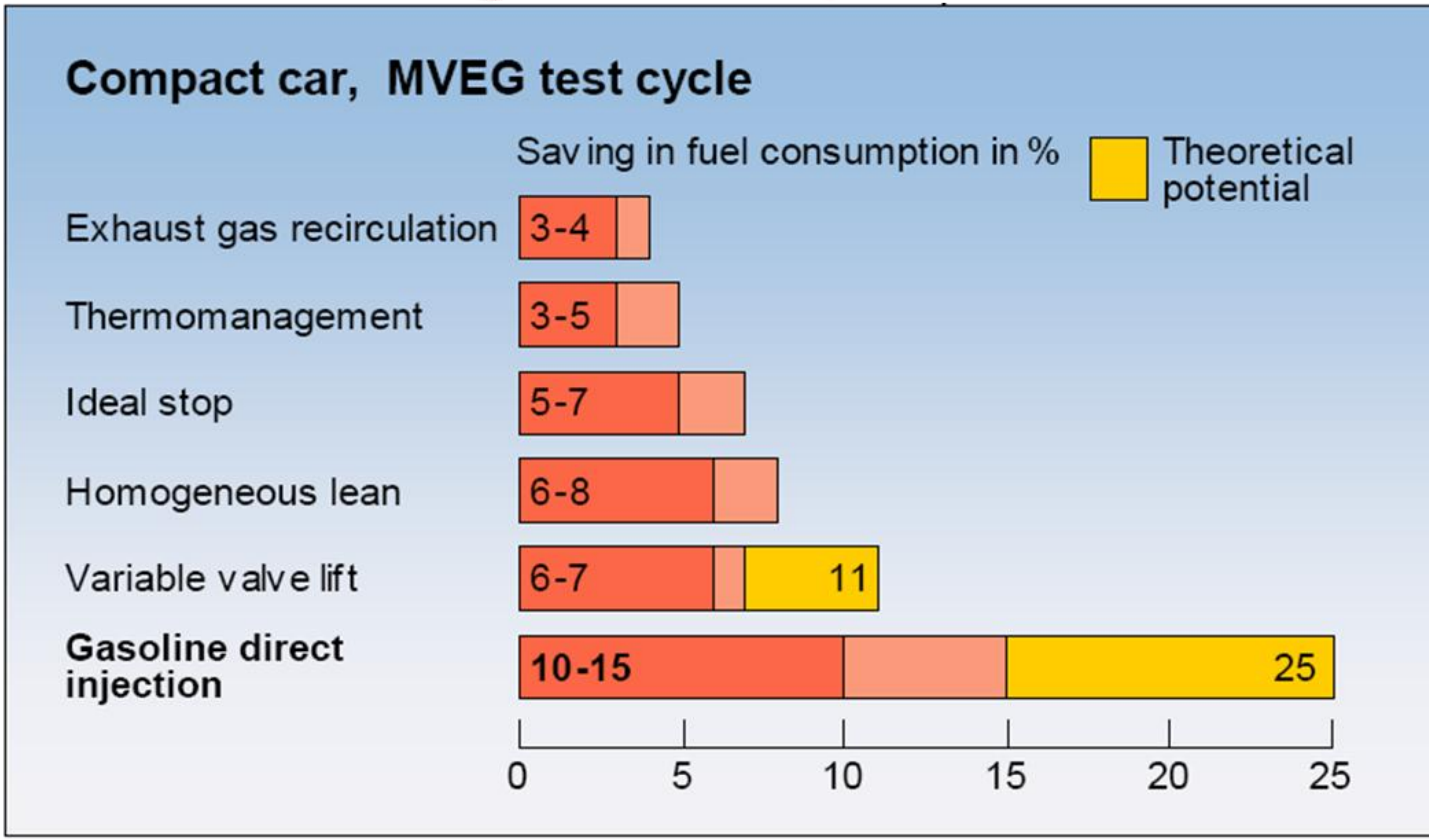


BOSCH

Courtesy of Robert Bosch LLC.

K3/P-BD 9143 e
K3/EAF7

Fuel Savings Comparision

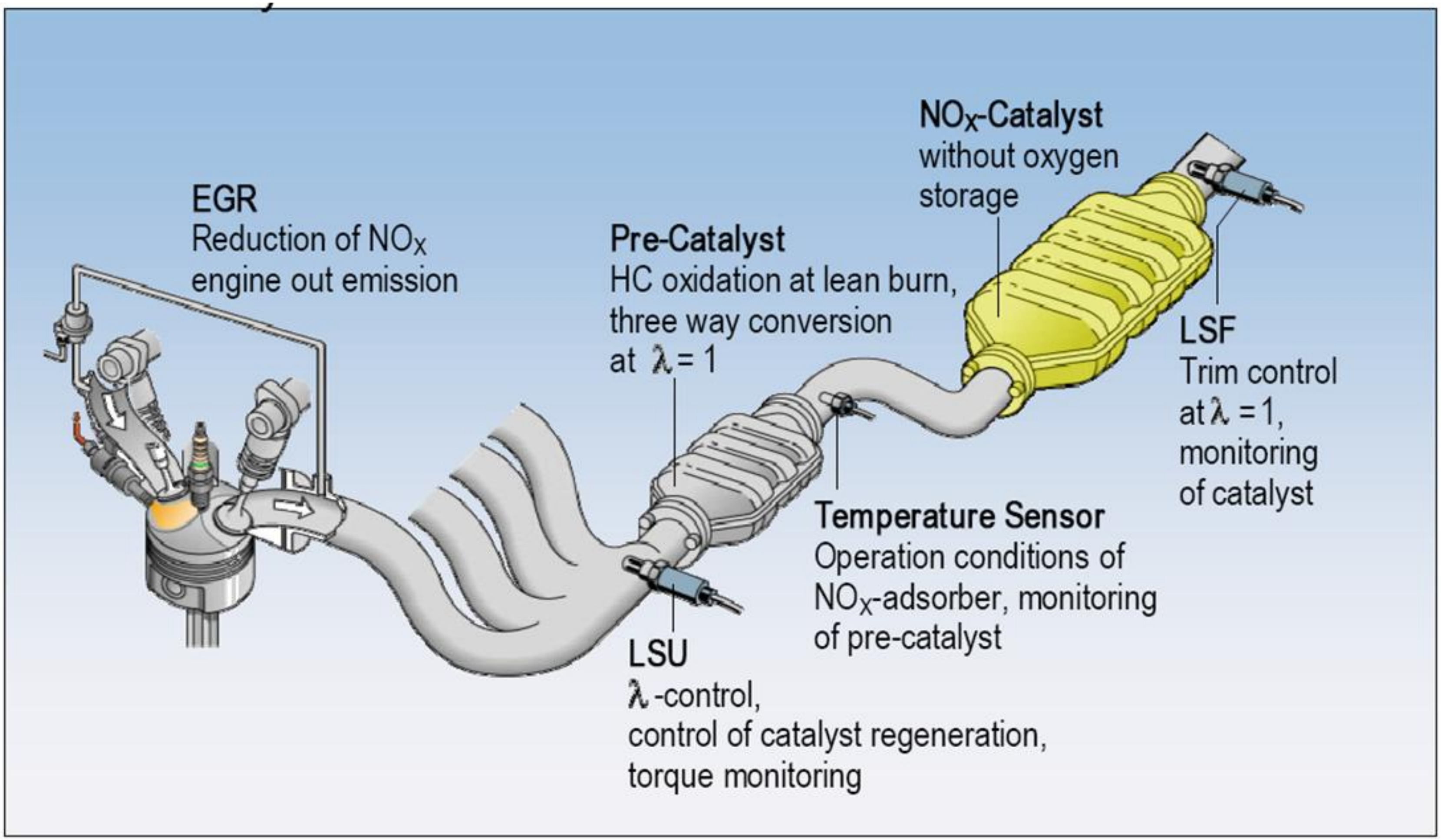


BOSCH

Courtesy of Robert Bosch LLC.

K3/P-BD 9144 e
K3/EAF7

Enlarged NOx Catalyst

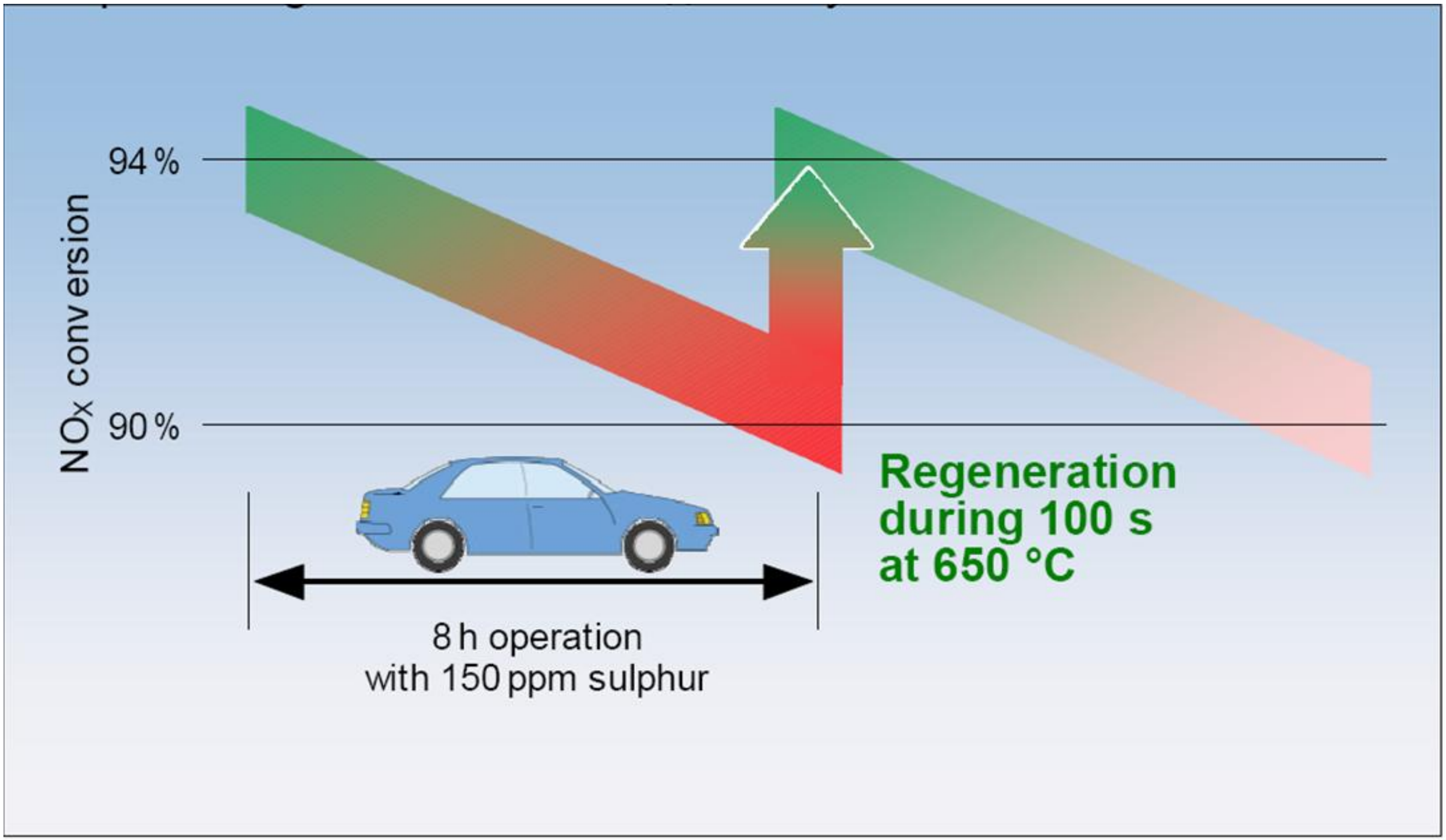


BOSCH

Courtesy of Robert Bosch LLC. K3/P-BD 9157 e

K3/EAF7

NOx Regeration

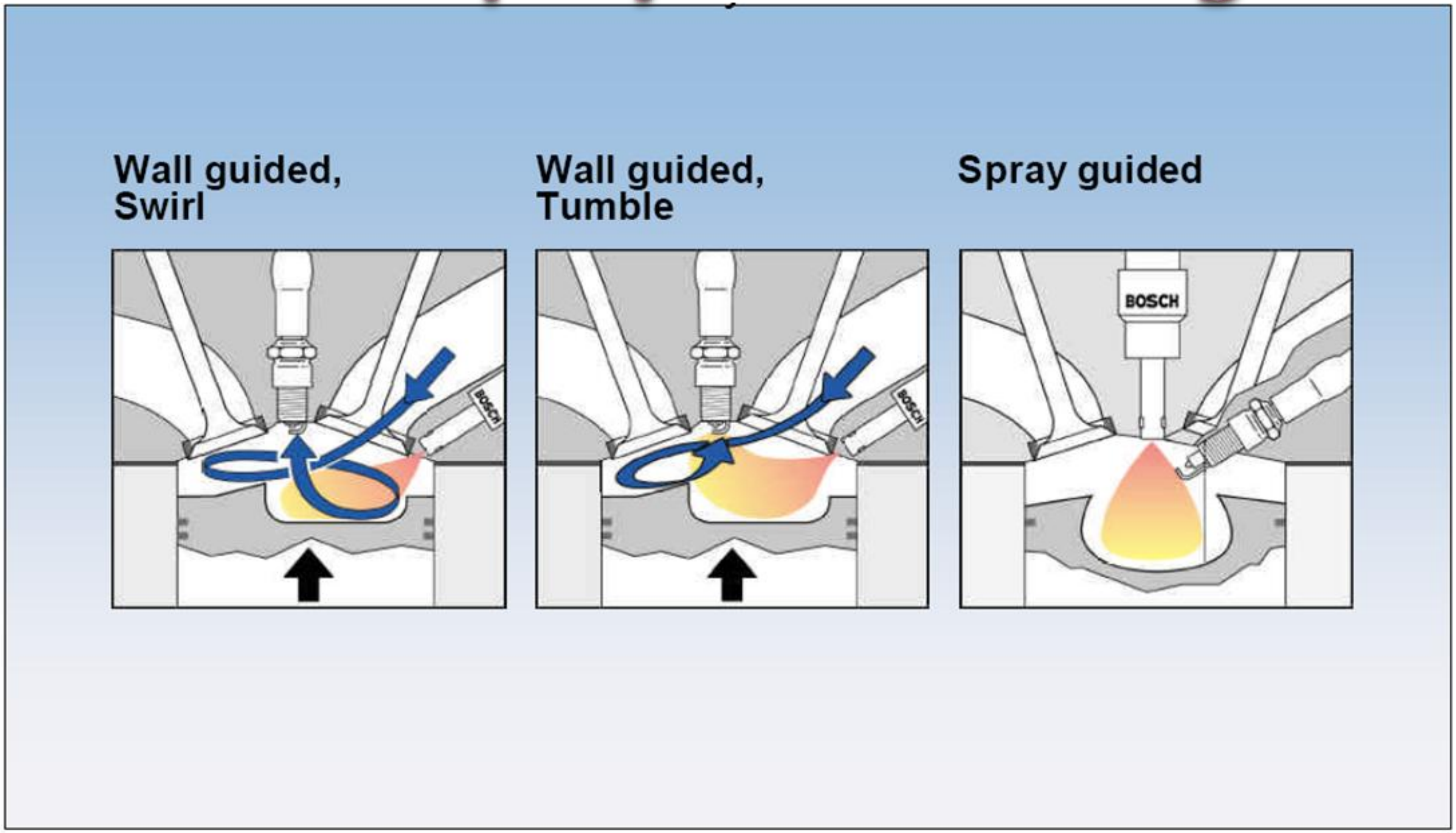


BOSCH

Courtesy of Robert Bosch LLC.

K3/P-BD 9158 e
K3/EAF7

Different Spray Guide Designs



BOSCH

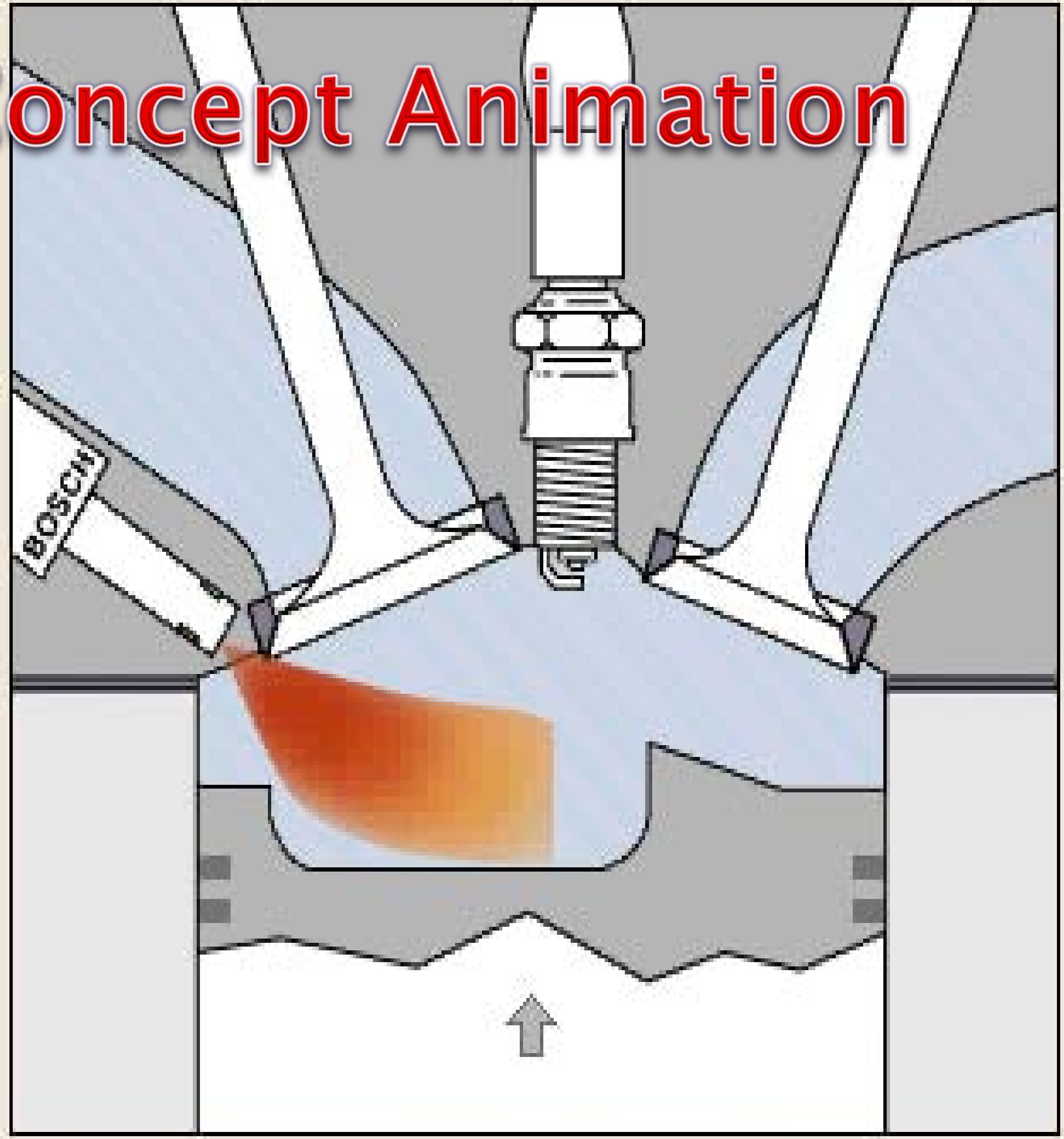
Courtesy of Robert Bosch LLC.

K3/P-BD 9148 e
K3/EAF7

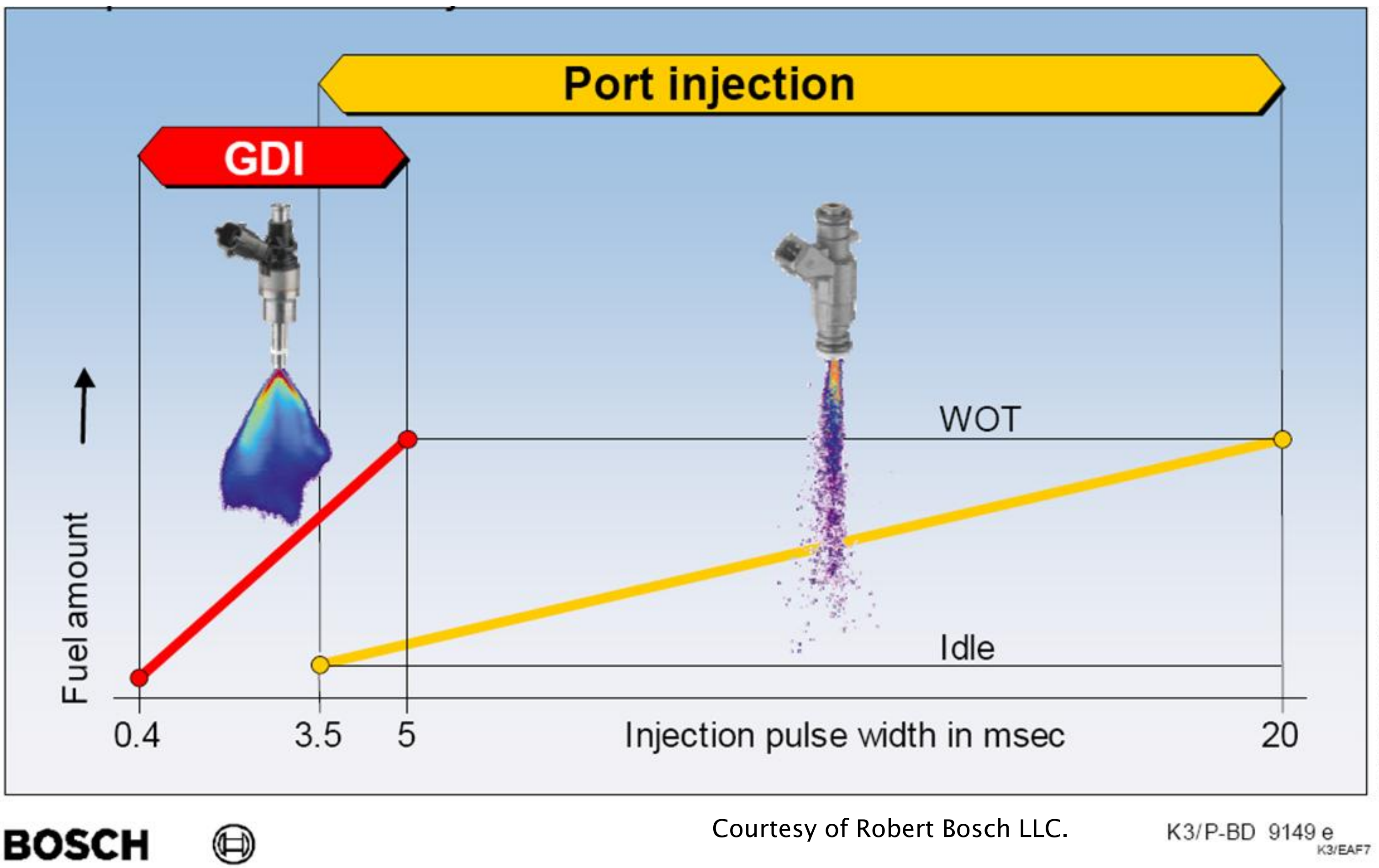
Tumble Concept Animation

Wall Guided Burn Concept - Swirl

Swirl Concept Animation



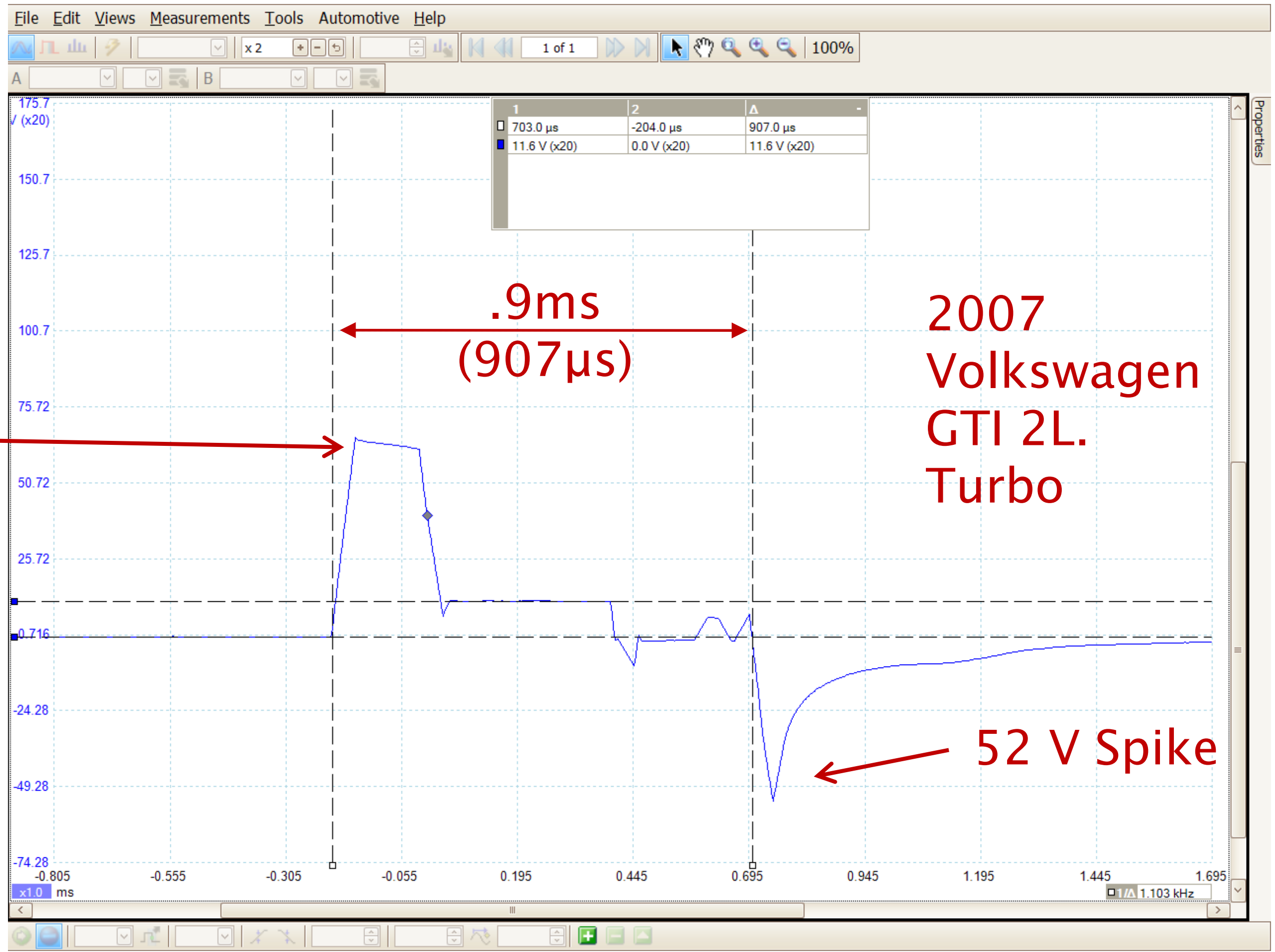
Pulse Width Times



Courtesy of Robert Bosch LLC.

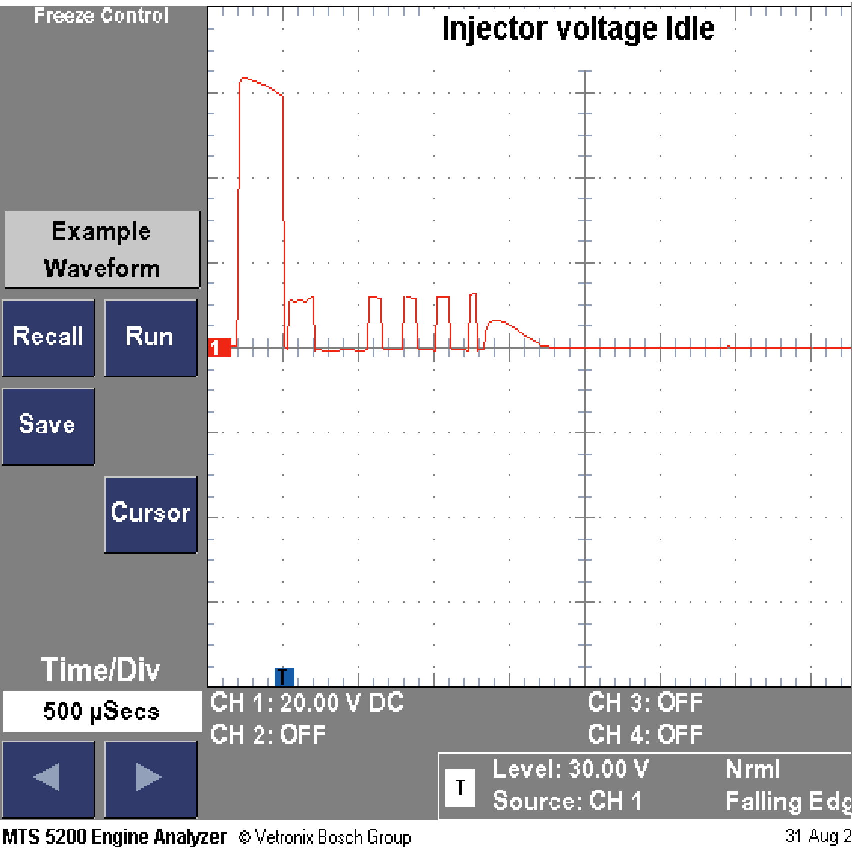
Injector Waveforms

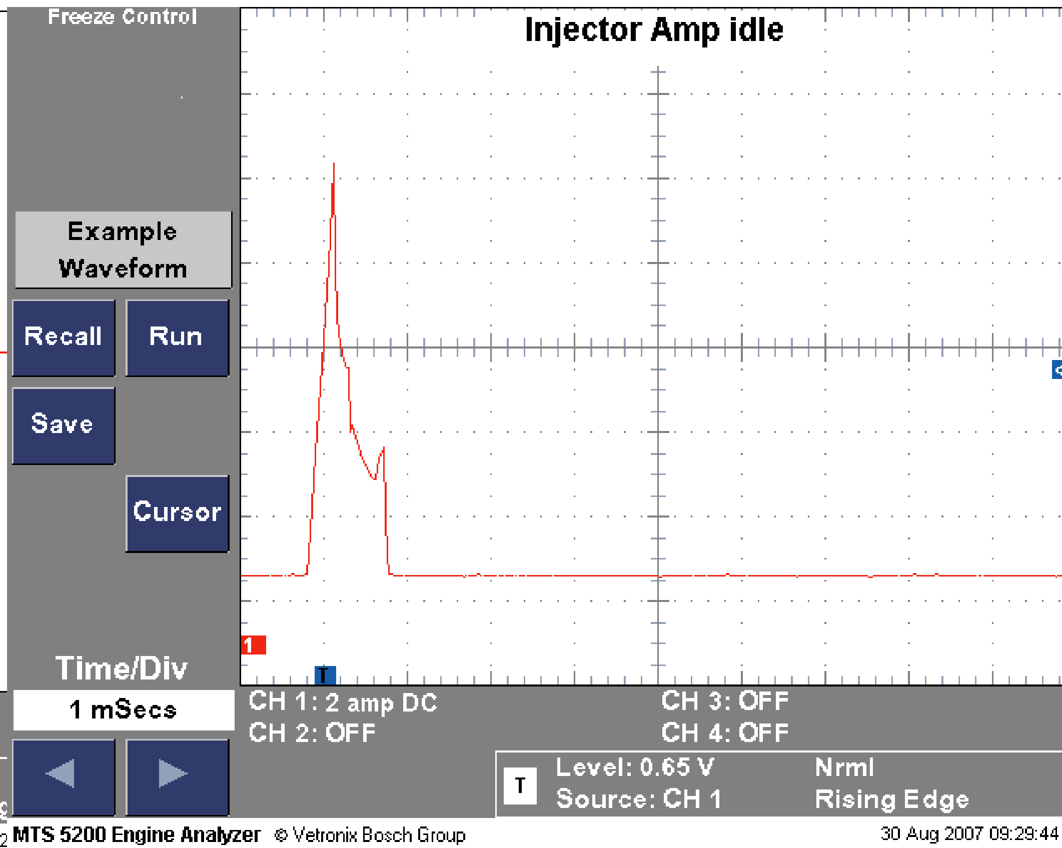
64 V capacitor discharge for initial injector opening.



Injector Waveforms @Idle

2006 VW Passat 2.0T

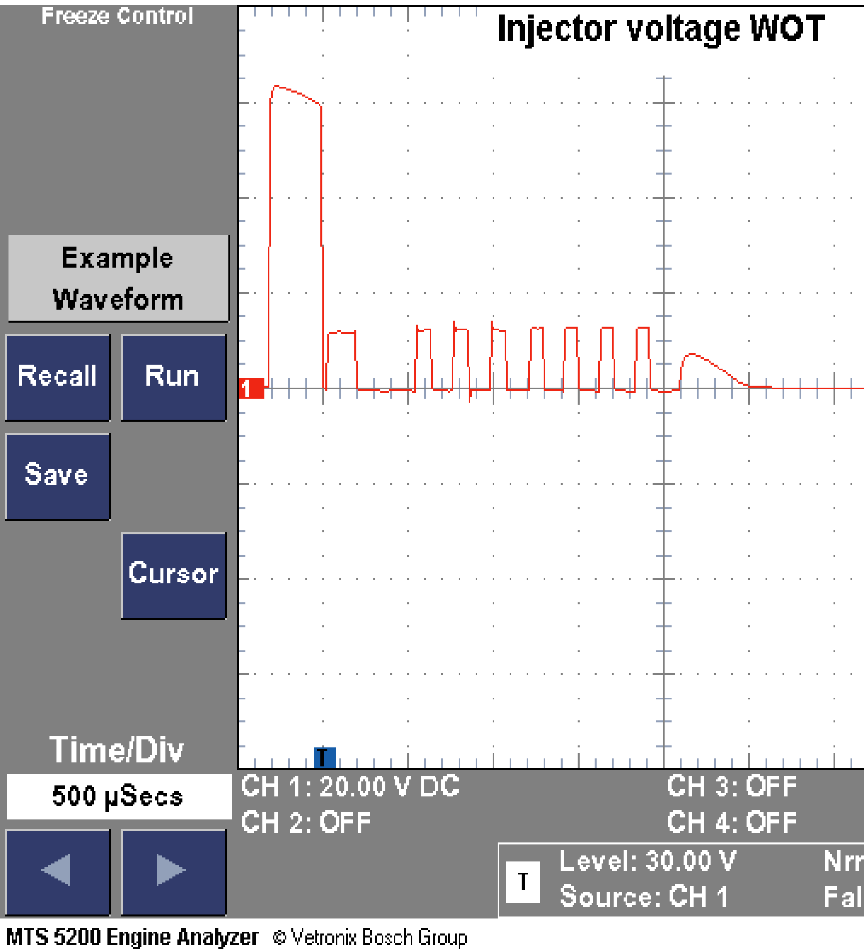


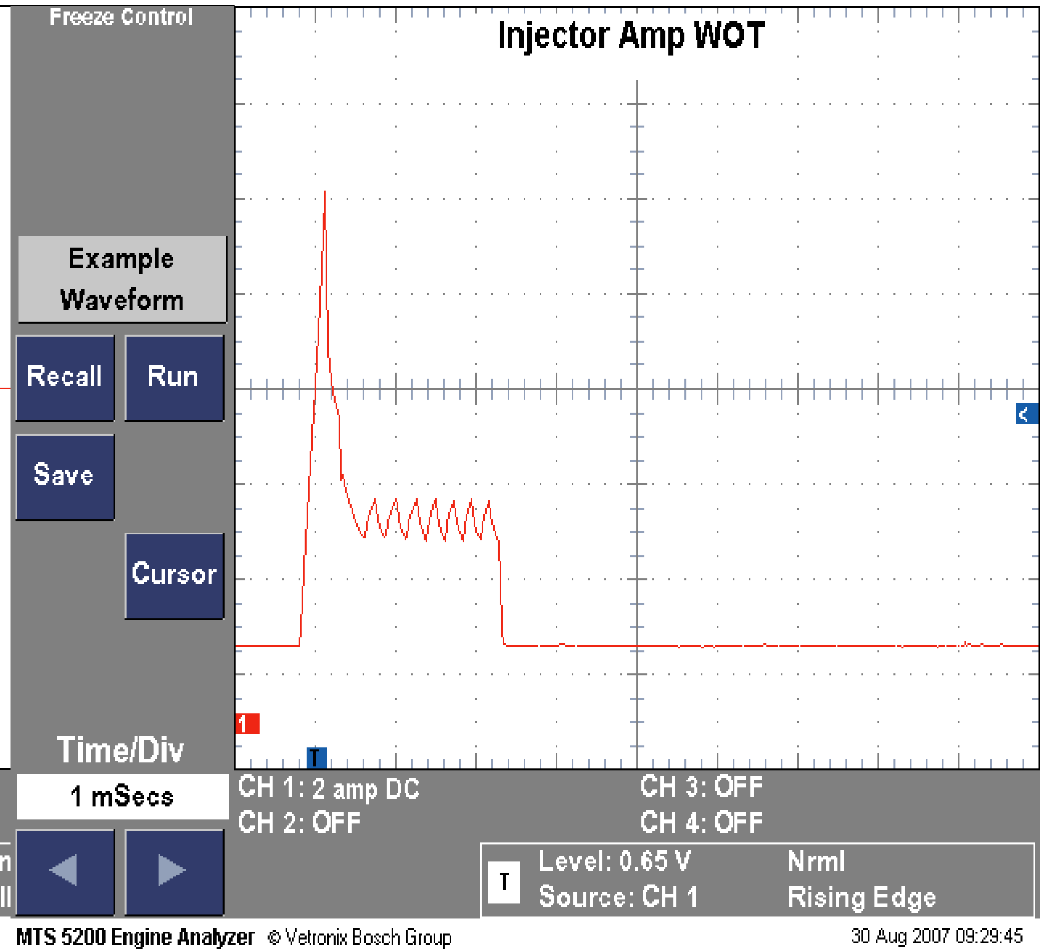


Courtesy of Robert Bosch LLC.

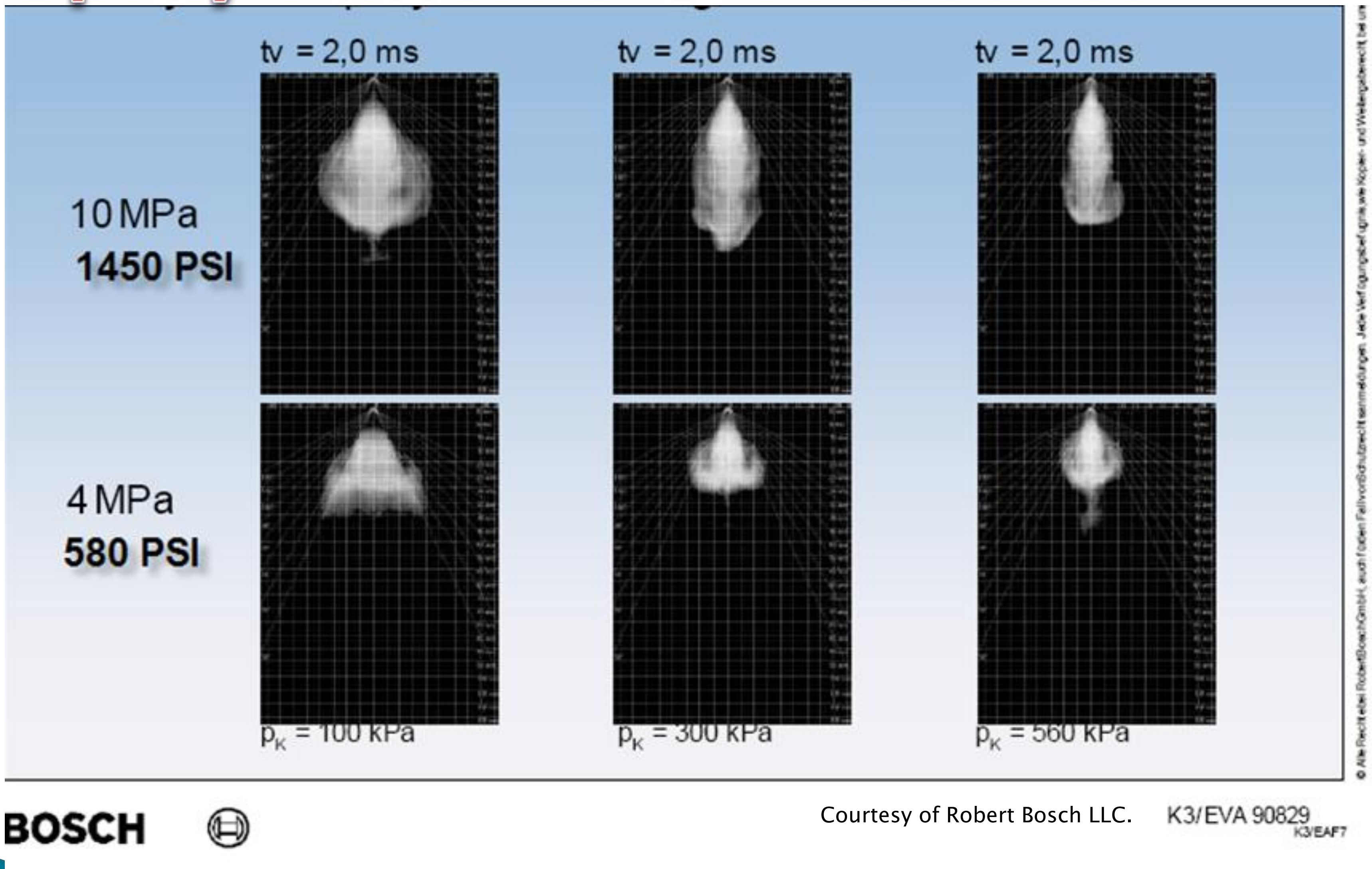
Injector Waveforms @ WOT

2006 VW Passat 2.0T



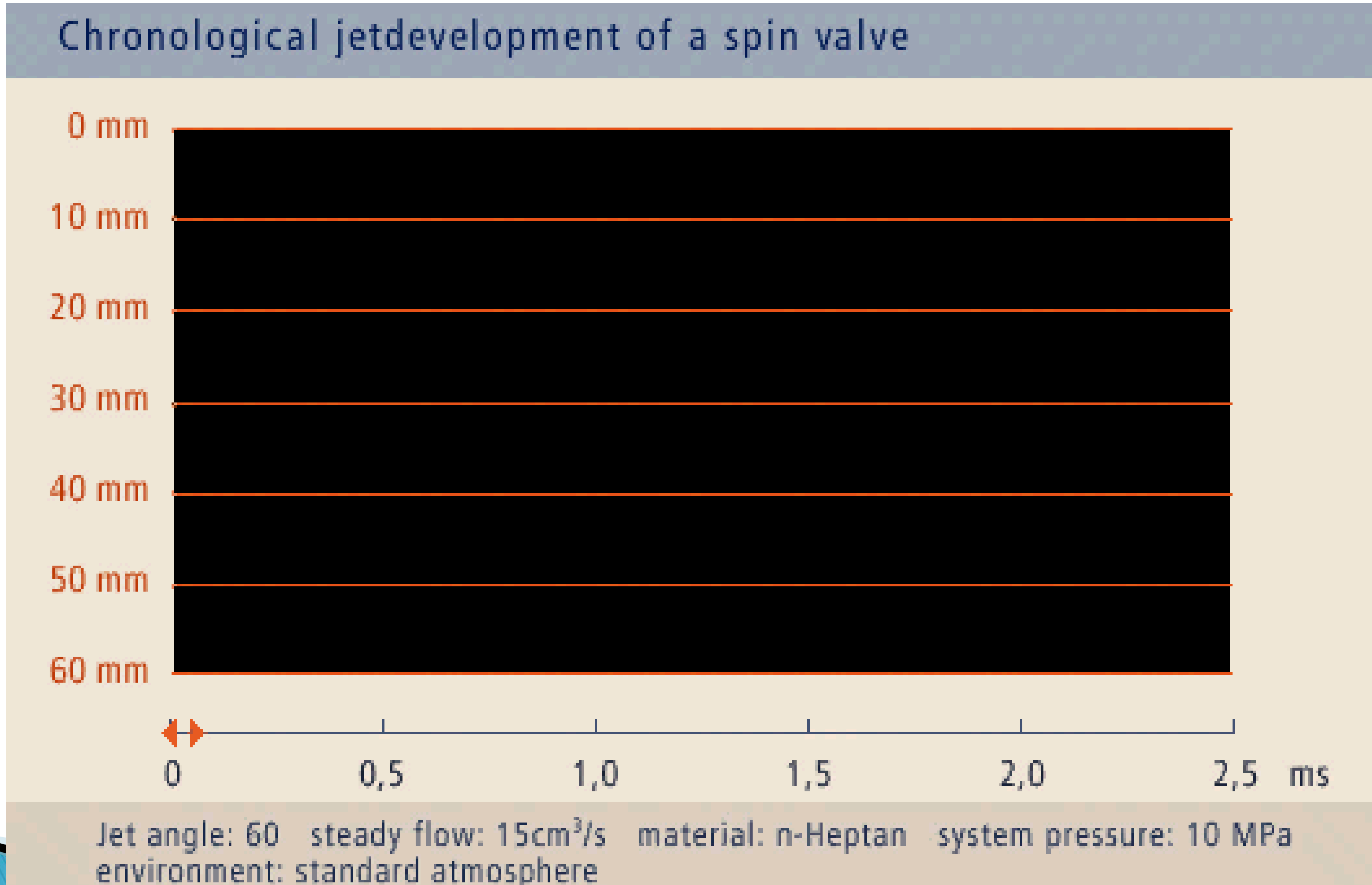


Spray Patterns @ Pressures



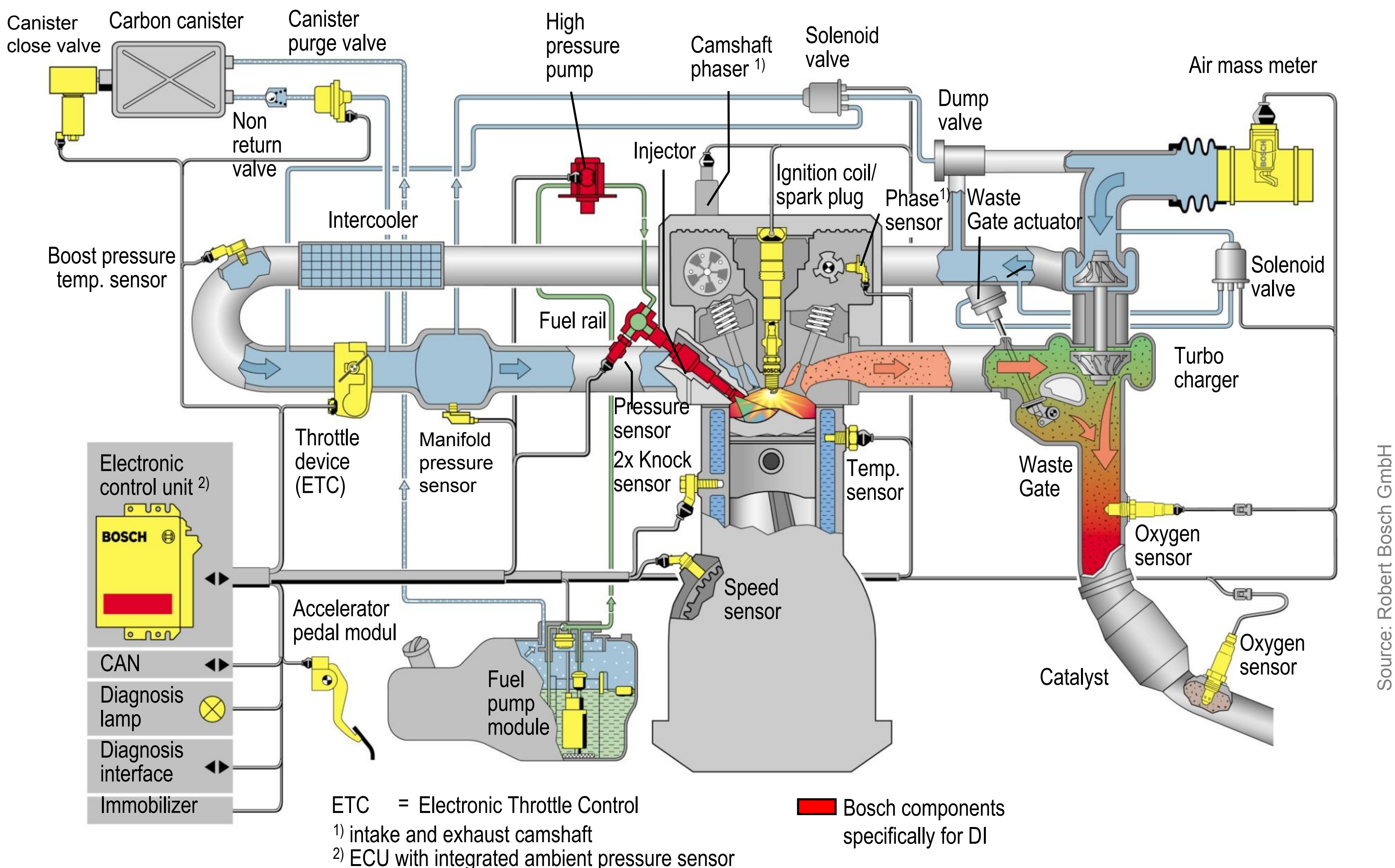
Courtesy of Robert Bosch LLC.

Vaporizing Fuel @ 10Mpa



Courtesy of Robert Bosch LLC.

GDI System Overview



Courtesy of Robert Bosch LLC.

Current Manufactures

- Audi
- Bosch GDI – Manifold Charge Valve
- Delphi
- Ford EcoBoost System – Turbo Charging
- General Motors
- Lexus – Hybrid Design (PFI & GDI)
- Mazda
- Mitsubishi
- ????

Delphi System

Operating pressure 120 bar to 200 bar. (1740-2900 psi)

Single-piston design.

Delphi Multec® Gasoline Direct Injection Fuel Rail with High Pressure Sensor

200 bar w/No Bounce

< .2 ms Between Multiple Injections Capability

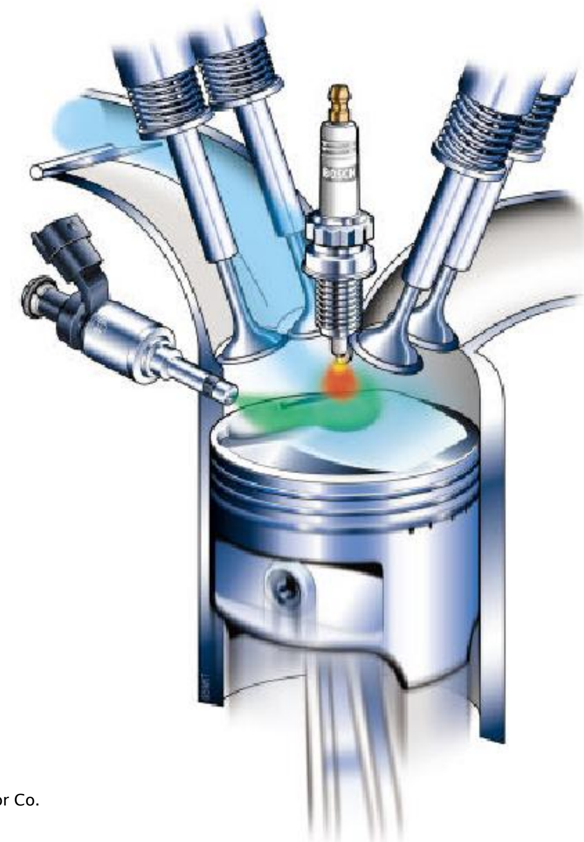
Delphi Multec® 20 GDi Fast Single Coil Fuel Injector

Courtesy of Delphi Corp.

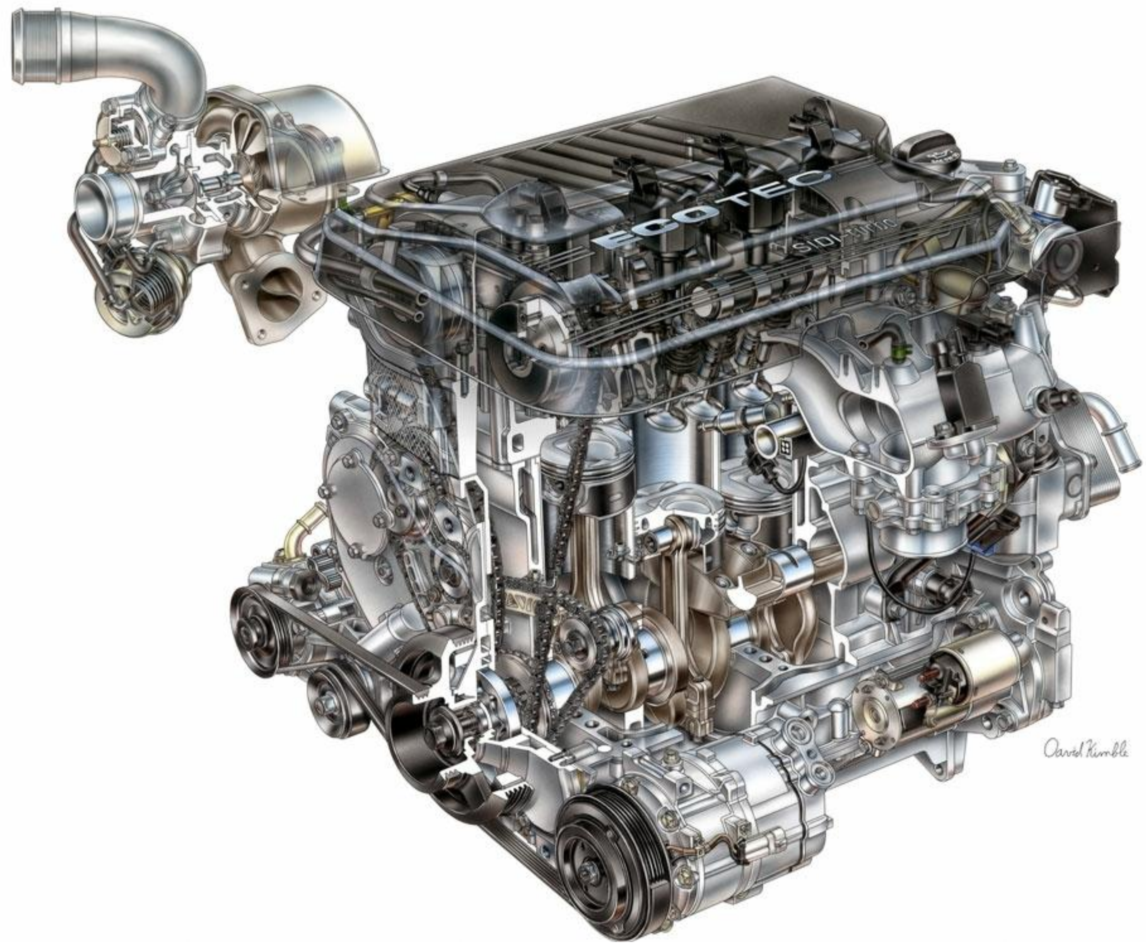
Ford EcoBoost

- 500K Cars/Year Next Five Years
- 3.5L = 340 HP/ 340 lb.-ft Torque
- 2 - 5 MPG over 4.6L
- 150 - 200 lb. Lighter
- Less Fuel Less CO_2

Courtesy of Ford Motor Co.



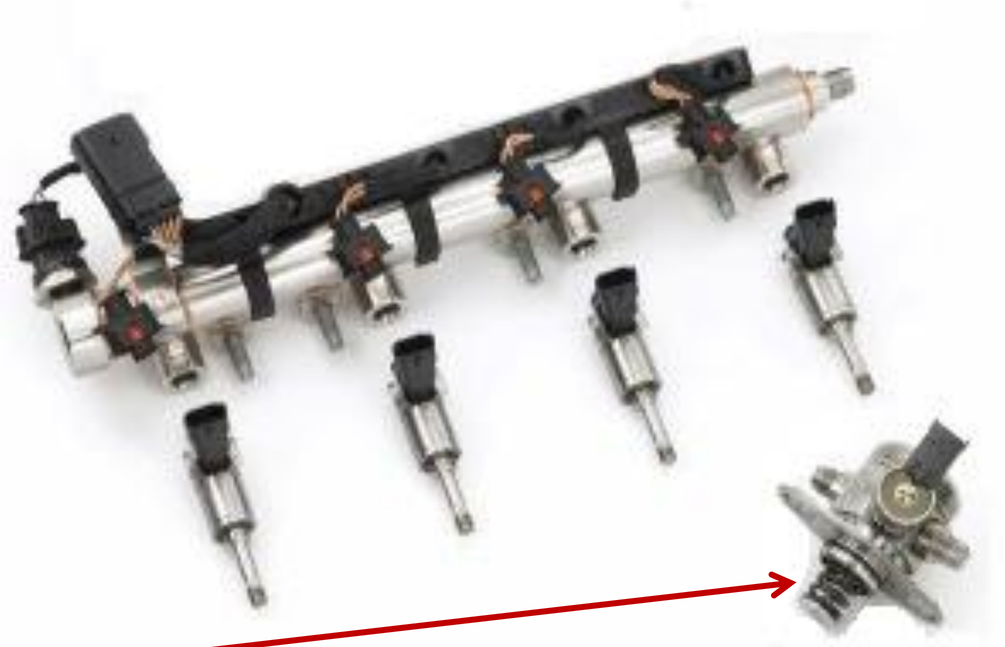
GM 2.0L SIDI Turbo



Courtesy of Robert Bosch LLC.

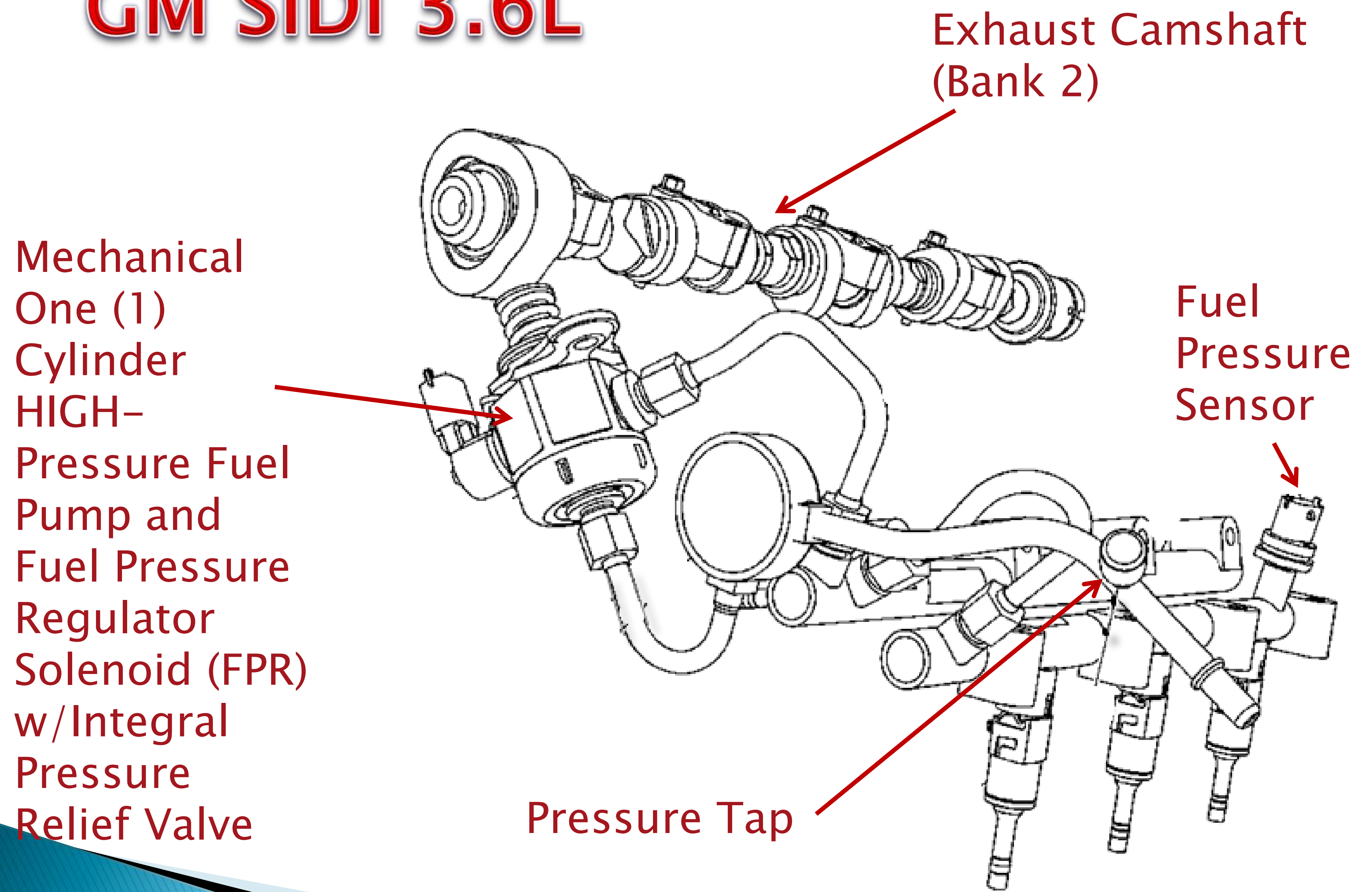
GM High Pressure Fuel System

- High pressure pump is driven off the camshaft (2150 psi, 140 bar)
- Fuel pressure regulator valve
- Rail-mounted fuel pressure sensor
- Integral pressure relief valve incorporated in HDP5 HP Pump



Courtesy of Robert Bosch LLC.

GM SIDI 3.6L



Courtesy of General Motors Corp

GM SIDI 3.6L

- 1 of 6 GM engines will be SIDI

- Features:
  1. Polymer-coated piston skirts
  2. 11.3-to-1 compression ratio.
  3. Closed-coupled catalytic converters.
  4. Fuel Pressure = Idle 35bar (508psi) to120bar (1740 psi)

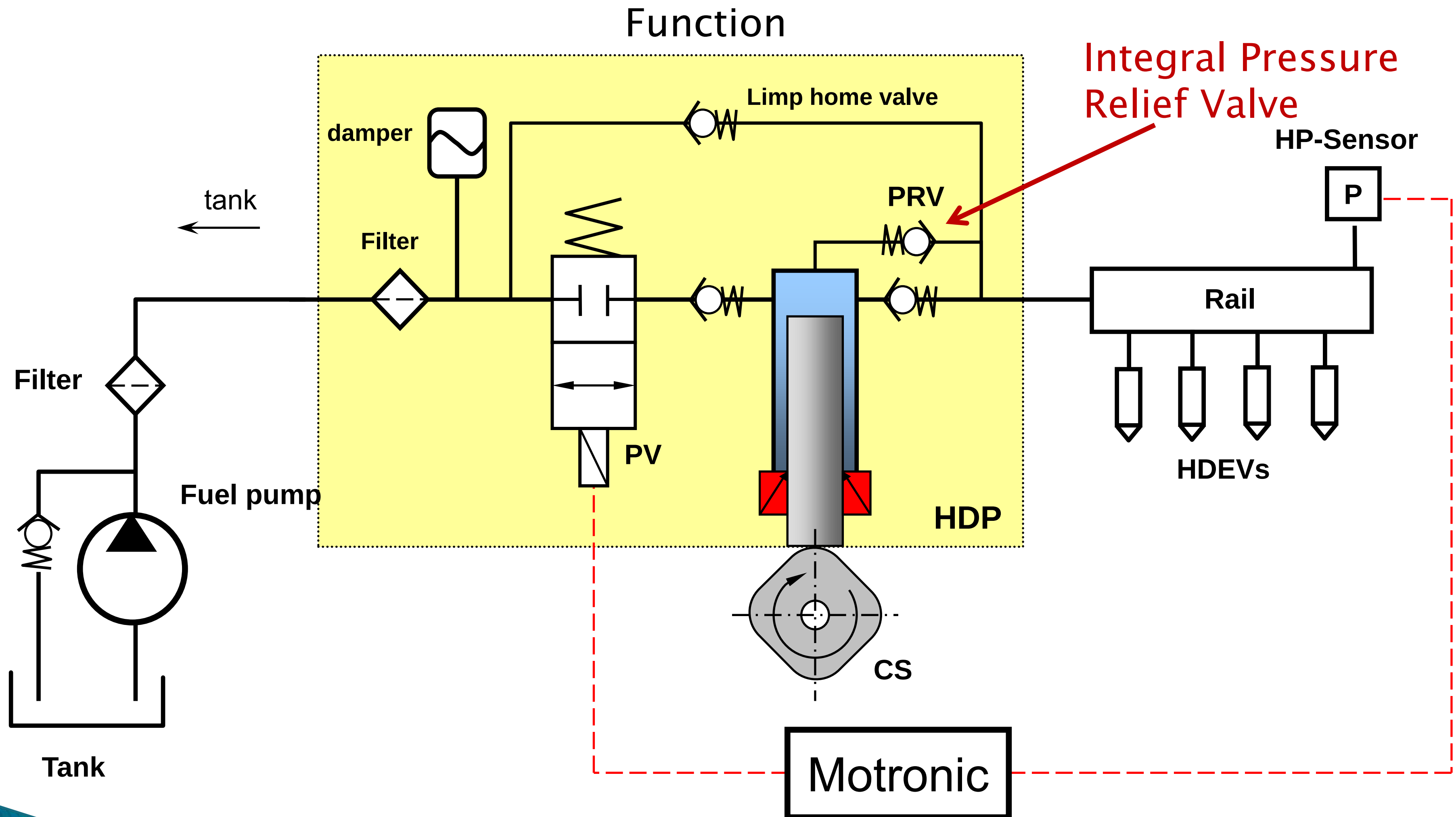
1.5 Ohms

Courtesy of Robert Bosch LLC.

GM SIDI 3.6L

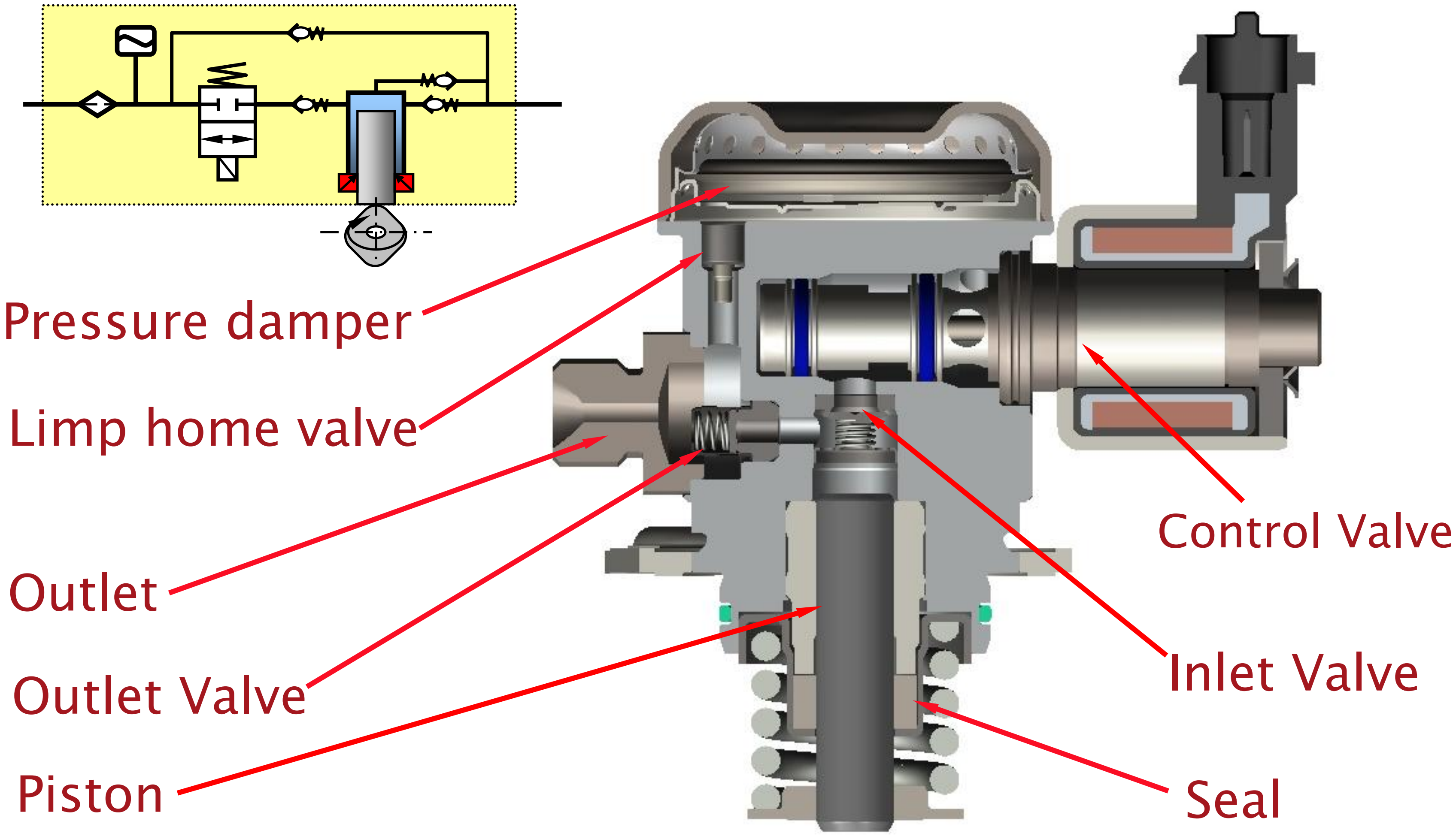
- **FPR:**
  - Spring pressure opened
  - ECM provides PWM B+ (high side driver) and ground.
  - Camshaft and crankshaft position sensor inputs synchronize the FRP regulator with the position of the eccentric on the camshaft.
  - Fuel Pressure Regulation
    - FPR is held open for a portion of each piston stroke displacing fuel back into low pressure side.
  - GM Service Manual is telling that story.

HDP5 High Pressure Pump



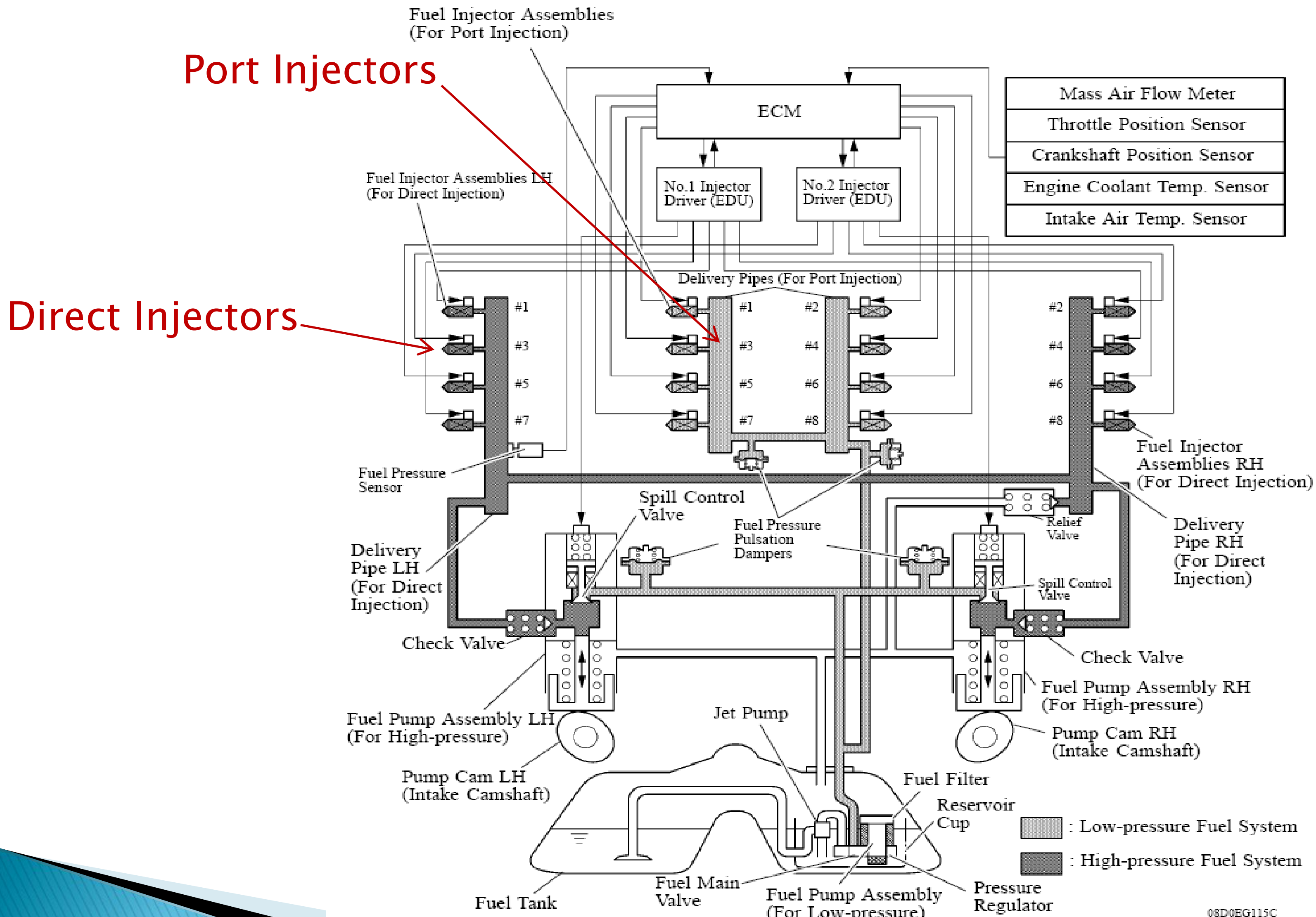
Courtesy of Robert Bosch LLC.

Cut-Away of HDP5

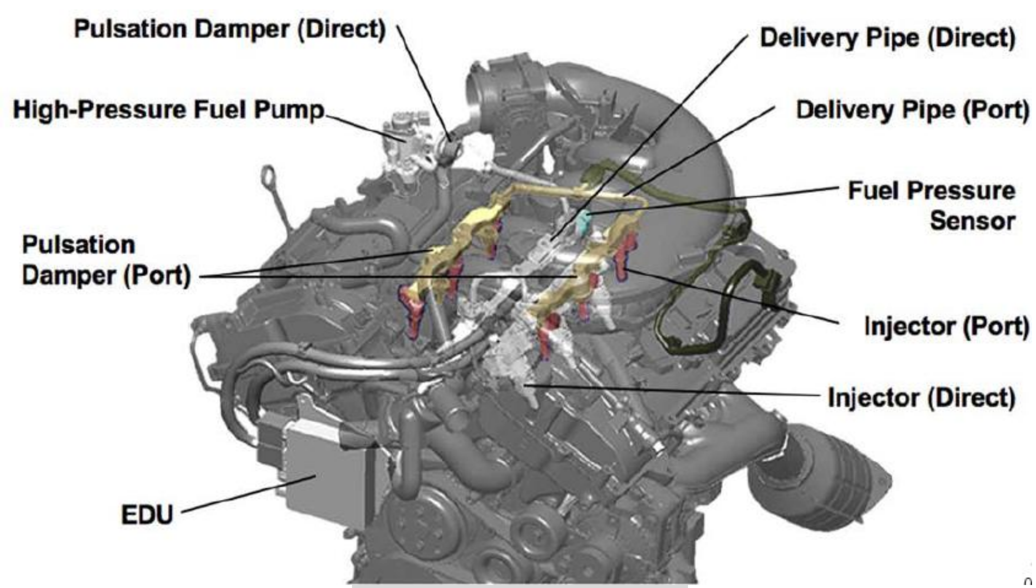


Courtesy of Robert Bosch LLC.

Lexus 2008 IS-F SFI D-4S (PFI/GDI)



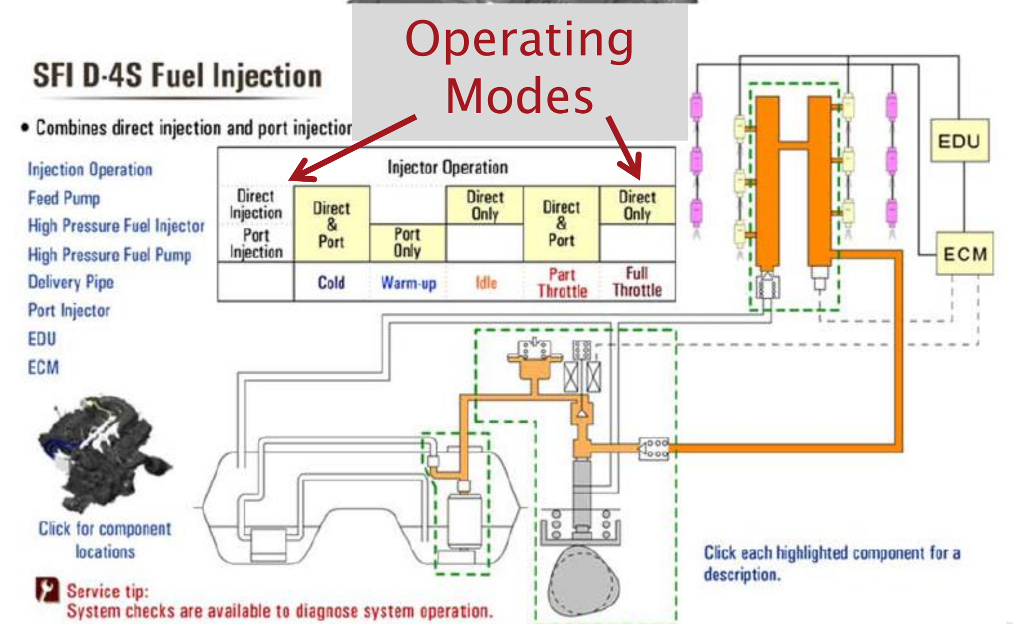
Lexus: Port and Direct Injectors



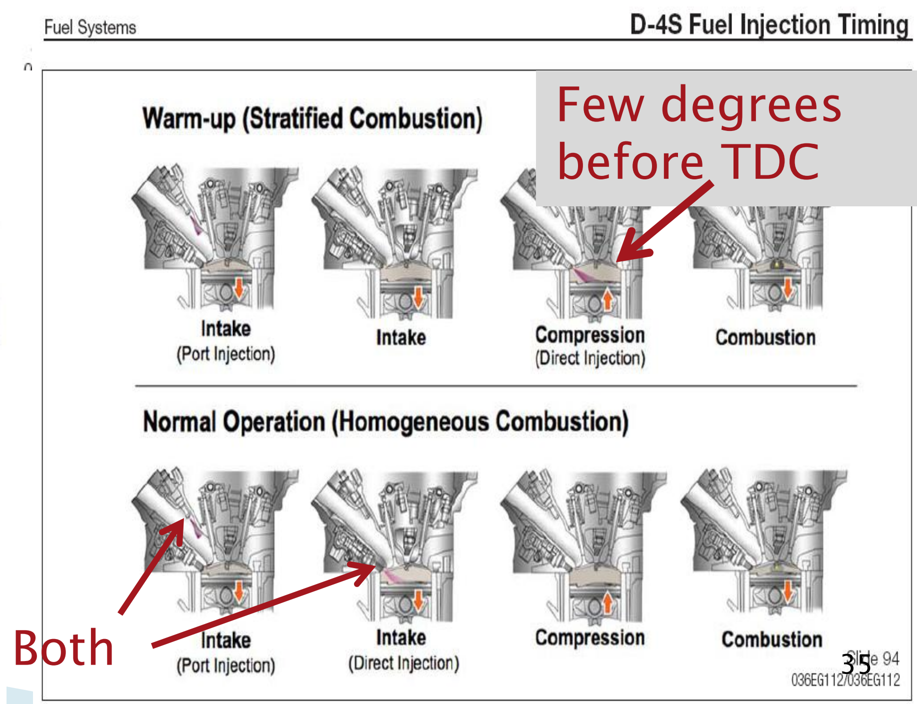
In-cylinder Injectors:

Pulsed-Timed individually to intake or compression stroke.

Port injectors:
Pulsed simultaneously, grouped, or sequentially according to operating conditions.



	Injector Operation				
Direct Injection	Direct & Port		Direct Only	Direct & Port	Direct Only
Port Injection		Port Only			
	Cold	Warm-up	Idle	Part Throttle	Full Throttle



Lexus 2 Modes of Operation

- **Stratified:**
  - Area around spark plug is richer then rest of cylinder.
- **Homogeneous:**
  - Fuel and Air are mixed through out cylinder.

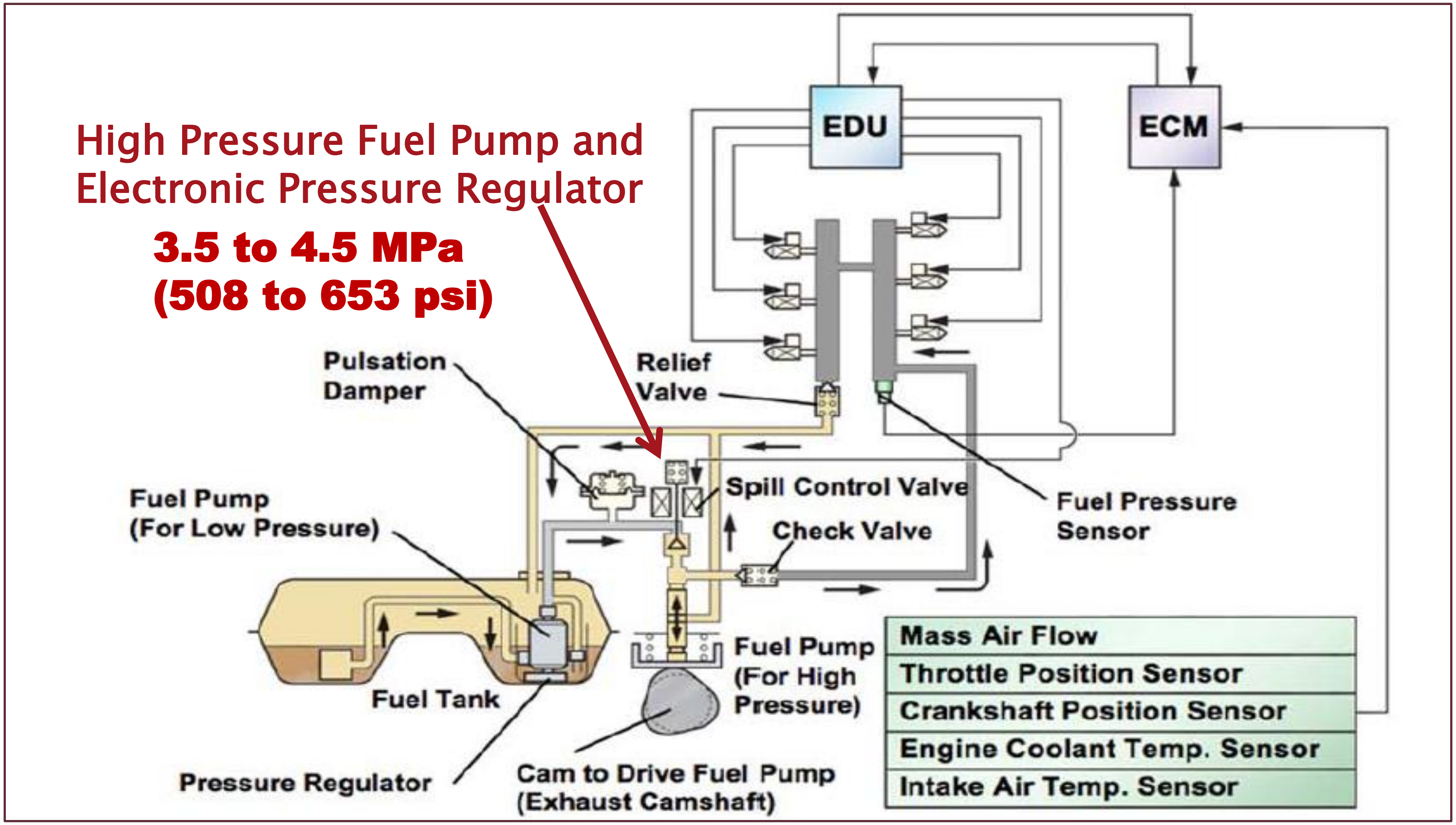
Stratified Mode

- **Exhaust Stroke**: Fuel Injected into Intake Port.
- **Intake Stroke**: Homogeneous Mix Enters Cylinder.
- **Compression Stroke**: Fuel Injected into Cylinder Just Prior to TDC
- **Ignition**: Fuel is Directed by Piston Contour Around Spark Plug. Rich Mix Easily Ignites to Burn Lean Mix in Rest of Cylinder.

Homogeneous Mode

- **Exhaust Stroke:**
  - Fuel Injected in Intake Port.
- **Intake Stroke:**
  - Homogeneous Mix Enters Plus Fuel is Directly Injected as Homogeneous Mix Enter Cylinder for Mix Correction.
  - Utilizes Heat Evaporation of Cooler Fuel = Higher Efficiency /Power.
- **Compression Stroke:**
  - Mixture is Compressed.

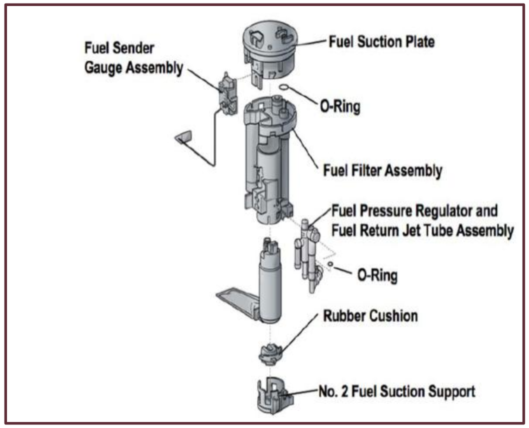
Lexus 2008 IS-F SFI D-4S

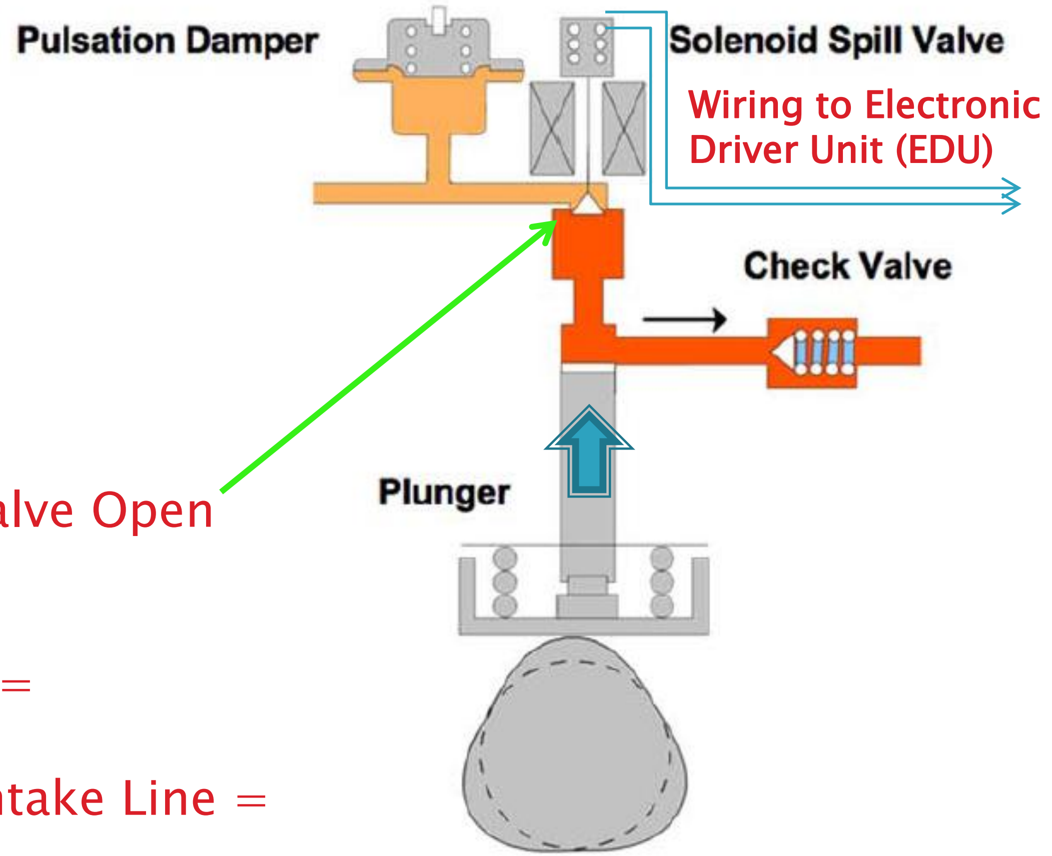


Lexus Fuel Delivery System

Mechanical High Pressure Pump

Electric In-Tank Transfer Pump





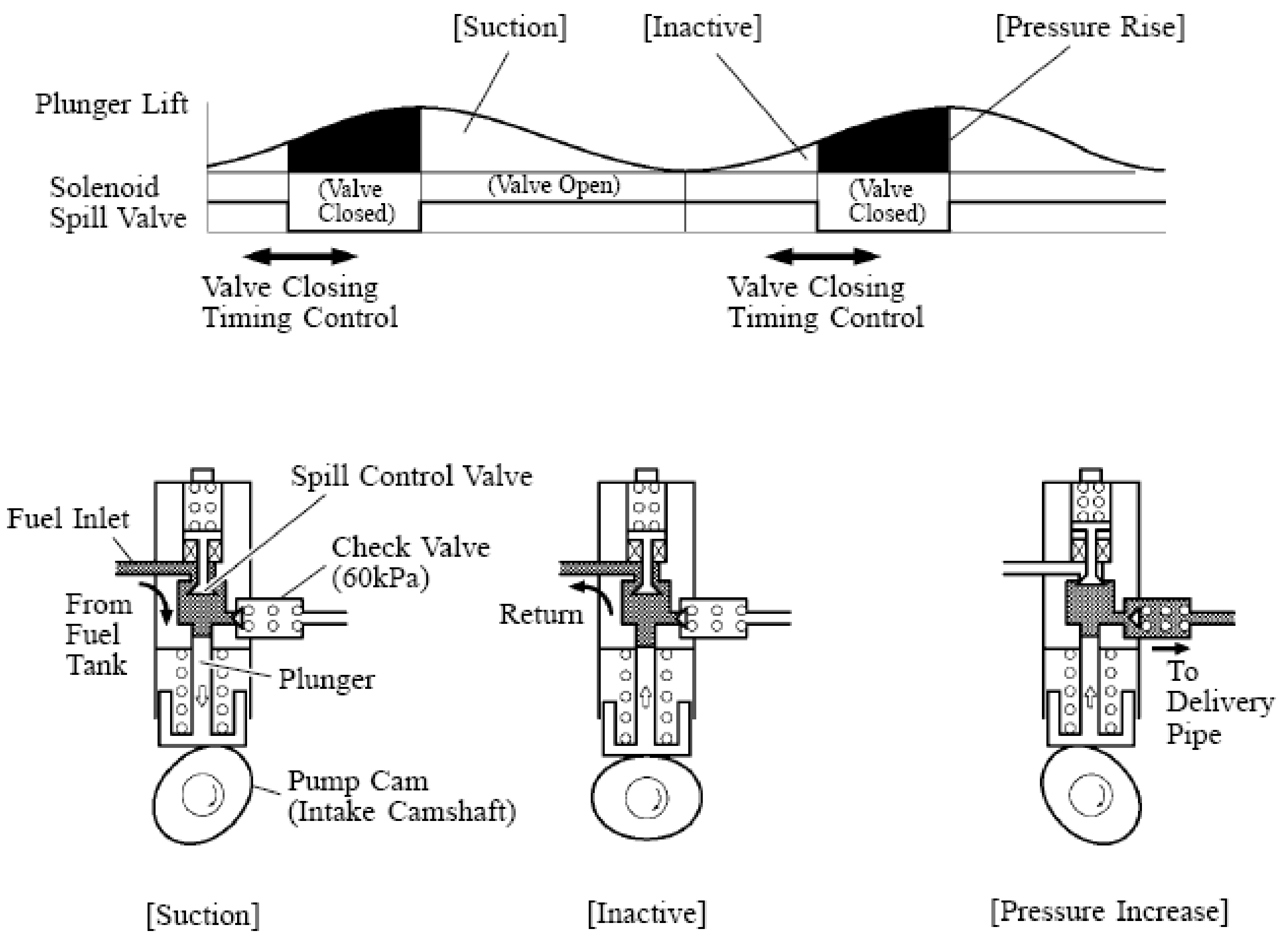
Computer Controls Spill Valve Open Duration.

Longer open Time =

More gas Pushed Back into Intake Line =

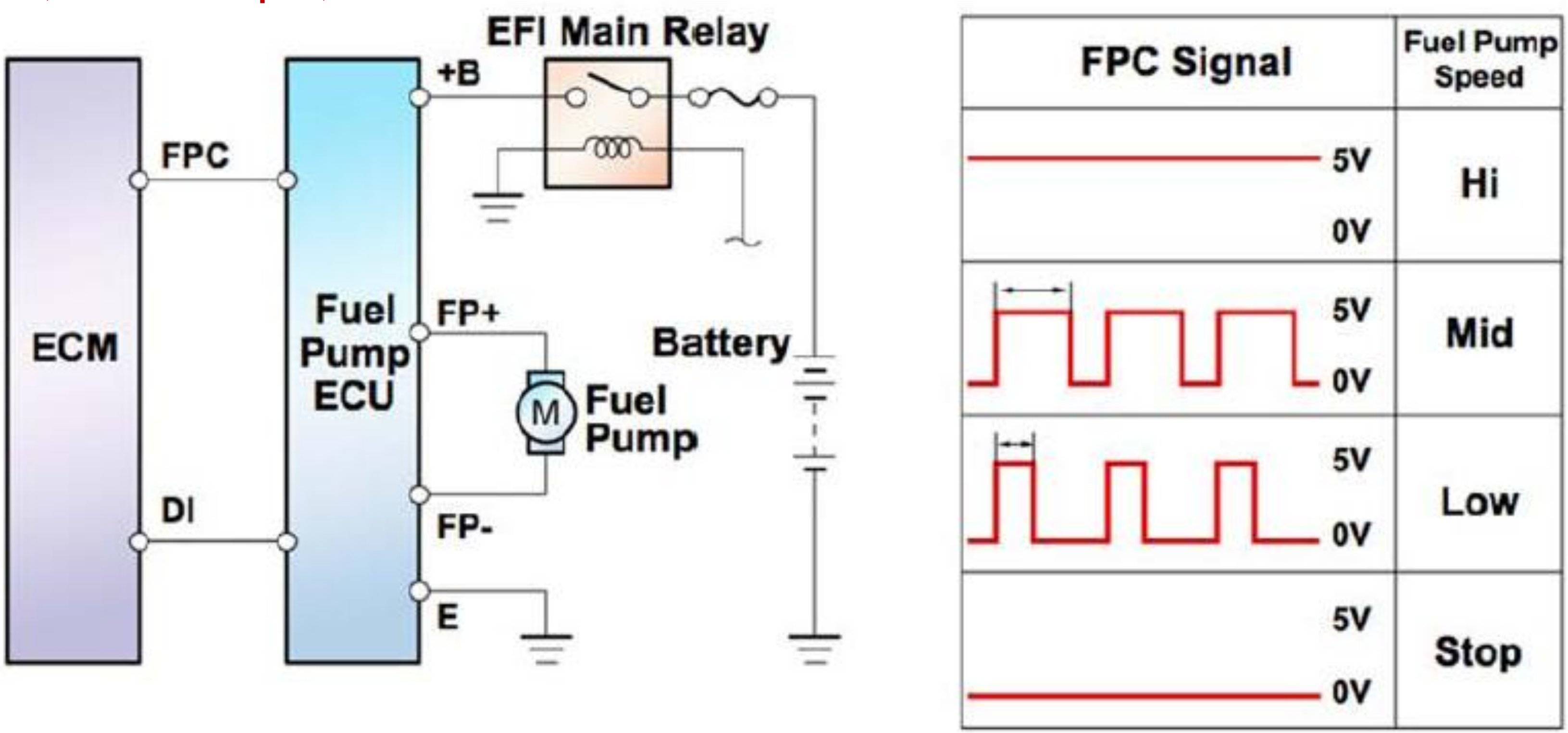
Less Pressure

PWM of FPR to Cam Position



Lexus SFI D-4S
Three Speed Fuel Pump Control

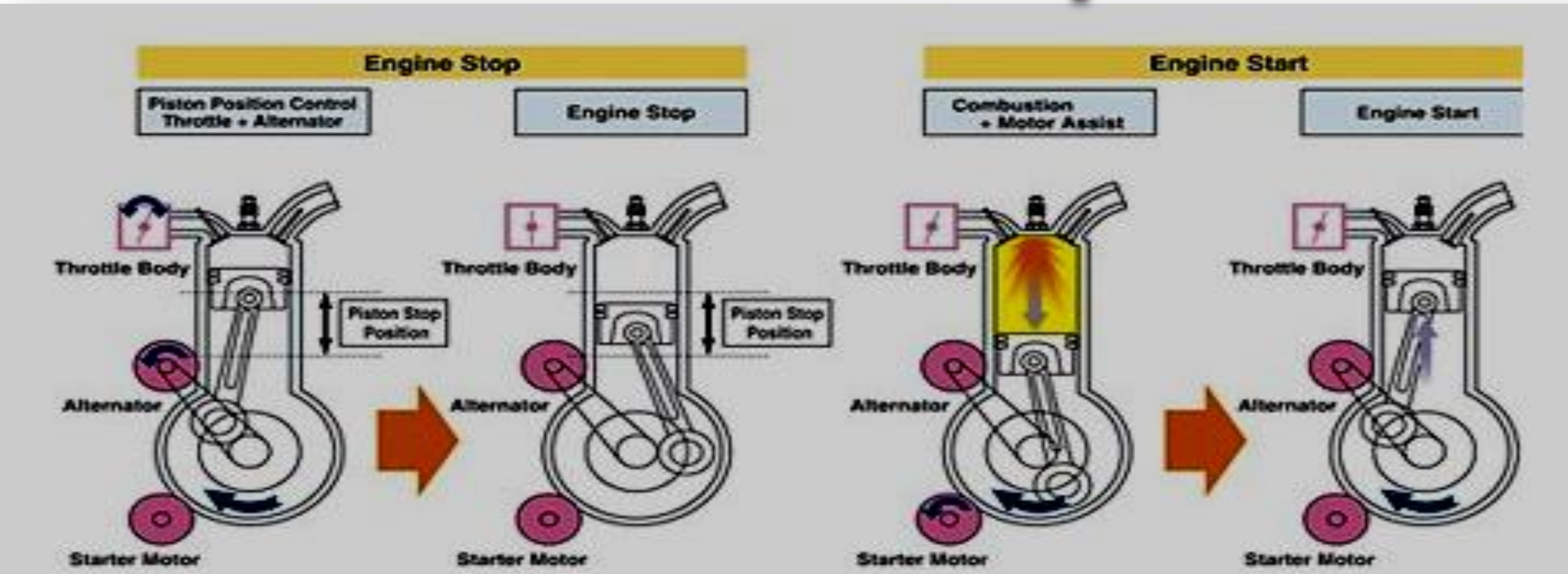
196 to 588 kPa
(28 to 85 psi)



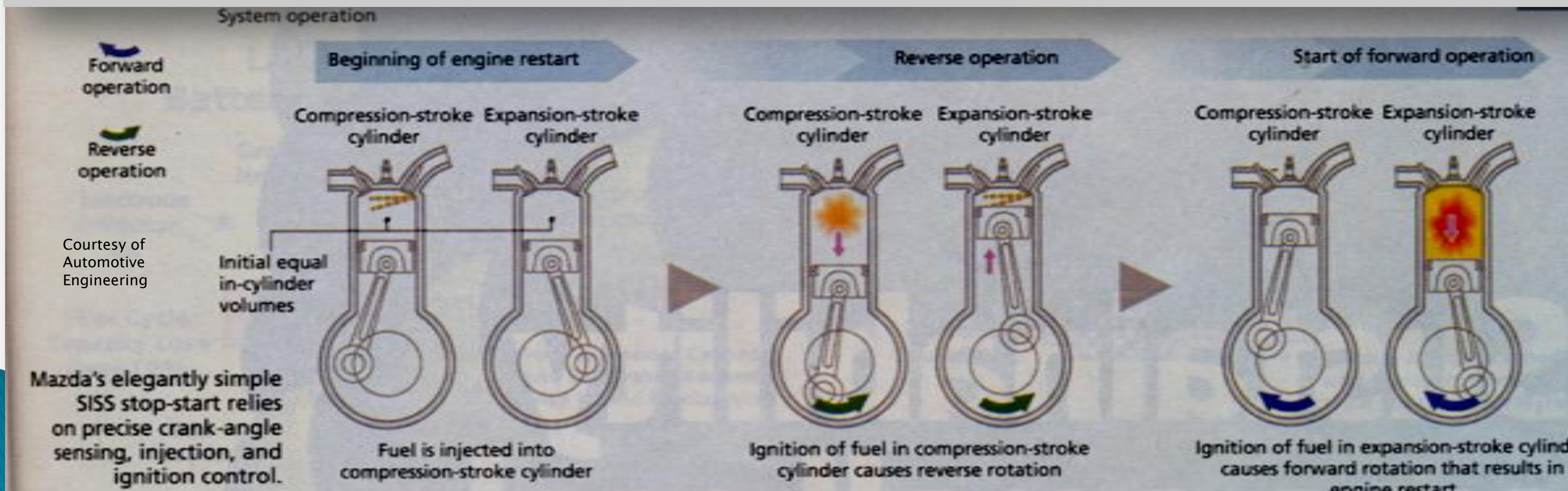
Mitsubishi Start-Stop System

- Smart Idle Stop System (SISS)
  - Restart in 0.35 seconds (1/2 time of electric motor)
  - 10% fuel savings.
  - No Electric Motor.
  - Uses Direct Injection + Spark

SISS: Different Concepts



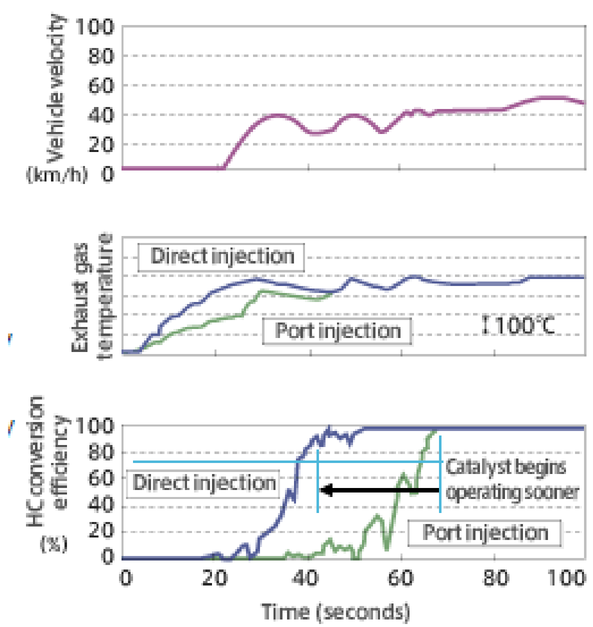
Courtesy of Green Car Congress



Courtesy of Automotive Engineering

Mitsubishi

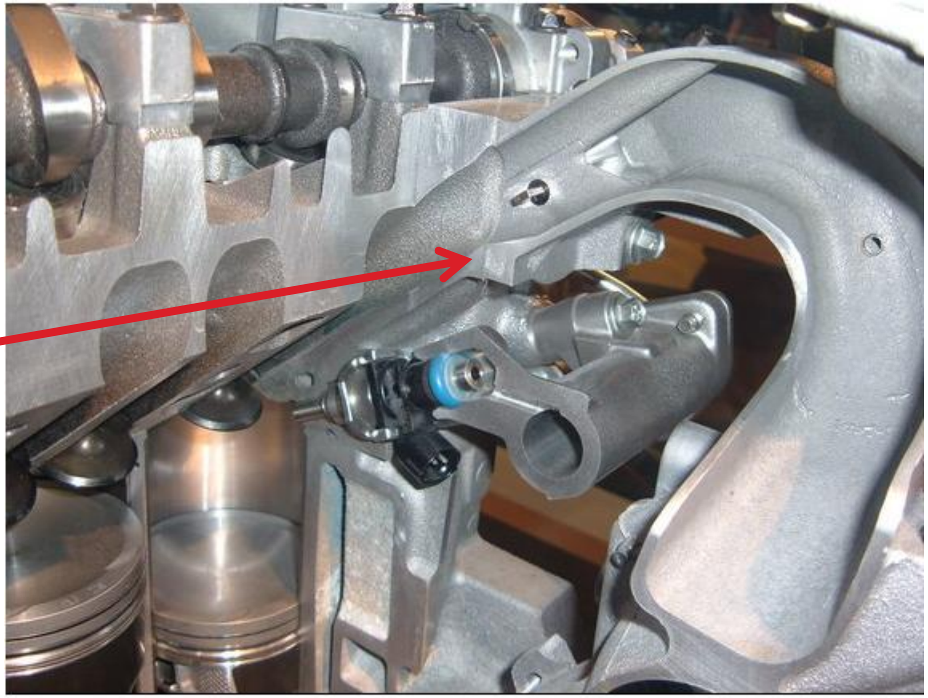
- **Two-Stage Combustion**
  - Late combustion fuel injection for catalytic warm-up
  - Exhaust gas temperature 700°C (1300°F).
- **Stratified Slight Lean Combustion**
  - Started few seconds after Two-Stage.
  - Immediate CO oxidation reaction.
  - Prevents CO poisoning.



Mazda DSIS 2.3L

Shared with Ford Escape, Focus, and Ranger.

Shaped
Intake Ports
•Low Restrictions
•Wall Guided Swirl



GM SIDI Fuel Pressure Relief

- W/O Scan Tool: WAIT at LEAST 2 hours after the engine has been run, before removing the high pressure fuel line.
- Use Scan Tool:
  - Command the low pressure fuel pump relay OFF.
  - Start the vehicle and allow the engine to idle until the engine stops. (20-30 seconds)
  - Using the scan tool, verify that there is little to no fuel pressure.

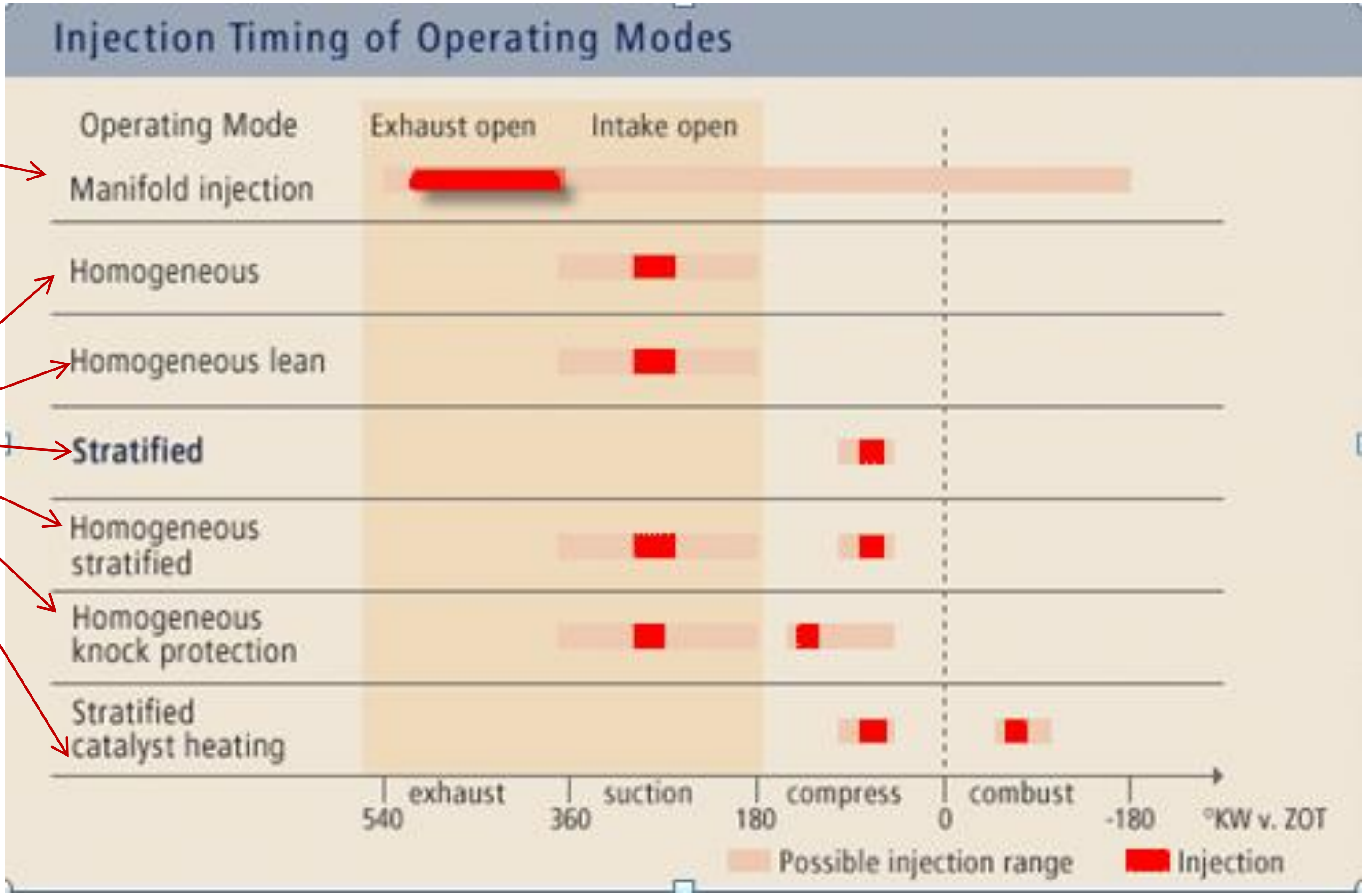
Bosch System

- Six Operating Modes
  1. Homogeneous
  2. Homogeneous Lean
  3. Stratified
  4. Homogeneous Stratified
  5. Homogeneous Knock Protection
  6. Stratified Catalysts Heating

Bosch Injection Timing Chart

PFI

6
Operating
Modes



Courtesy of Robert Bosch LLC.

Homogeneous Mode

- 14.7-1
- Throttle Controlled.
- Single Injection
- Even Mixture Across Chamber
- Used for High Torque/High Speed

Courtesy of Robert Bosch LLC.

Homogeneous Lean Mode

- Smooth Switch (Stratified/Homogeneous)
- Throttle Controlled
- Charge Motion Valve Closed
- Lambda >1 (excess air)
- Single Injection
- Less Fuel Consumption
- Some Torque/Speed Loss

Courtesy of Robert Bosch LLC.

Stratified Mode

- Throttle Valve is Wide Open
- Charge Motion Valve Closed
  - Ram-Air Swirl Effect
- Injection Just Before Spark
  - Lean Combustion
- Occurs Only Around Plug
  - Low Cylinder Wall Heat Loss
- Disadvantages
  - Limited Torque/Speed
  - Soot Formation & Short Mixture Prep Time.
- Advantage
  - 20% Fuel Conservation = Less Emissions

Courtesy of Rober LC.

Homogeneous Stratified Mode

- Throttle Opening Charge Motion Valve Closing
- Double Injection
  - 1 on Intake Stroke & 1 on Compression Stroke
- Lean Mix w/Rich Mix Around Spark Plug
  - Rich mix burns Lean mix
- Advantages:
  - Smoothes Switch Between Modes
  - Decreases Emissions w/Smooth Torque
  - Less Fuel than Homogeneous Lean Mode
  - Lower Emissions than Stratified Mode

Courtesy of Robert Bosch LLC.

Homogeneous Knock Protection Mode

- Charge Motion Valve Open
- Increases Knock Limit at Lower RPMs
  - Useful at full load
- 2 Injections
  - 1 on Intake (homogeneous lean)
  - 1 on Combustion (target desired Lambda)
- Combustion Injection Lowers Mix Temp
- Lowers Need for Retarding Timing
- Lowers Emissions & Fuel Consumption

Courtesy of Robert Bosch LLC.

Stratified Catalyst Heating Mode

- Charge Motion Valve Closed.
- Fast Warm-Up of Catalyst System
  - Pre-catalyst & NOx Catalyst.
- 2 Injections
  - 1 just before combustion (stratified mode).
  - 1 just after combustion (heats exhaust).
- Used to De-Sulfurize NOx Catalyst
  - 1200°- 1300° F.

Courtesy of Robert Bosch LLC.

Questions?

Website:
http://www.siucautomotive.com/autoindex.html

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