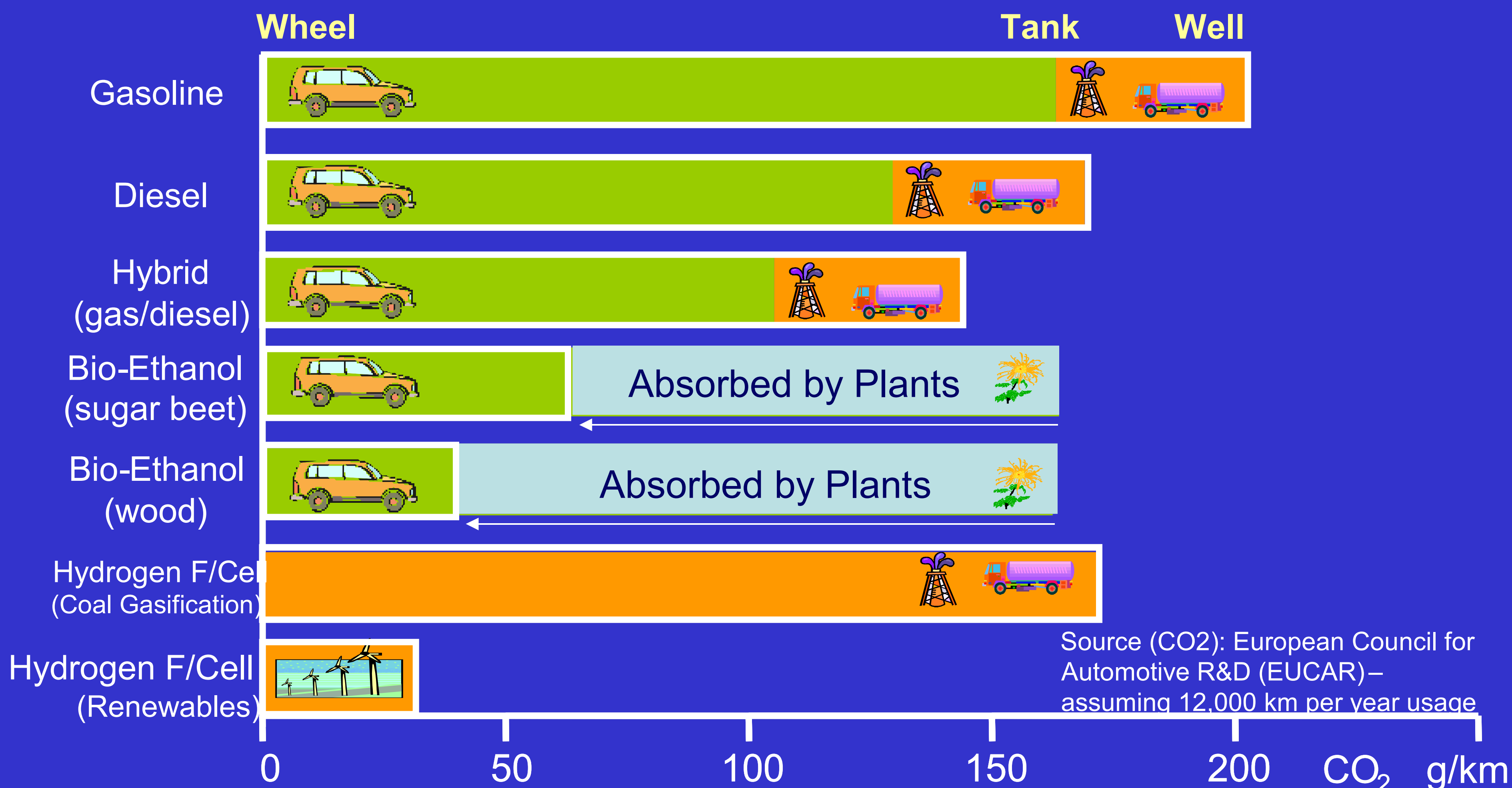
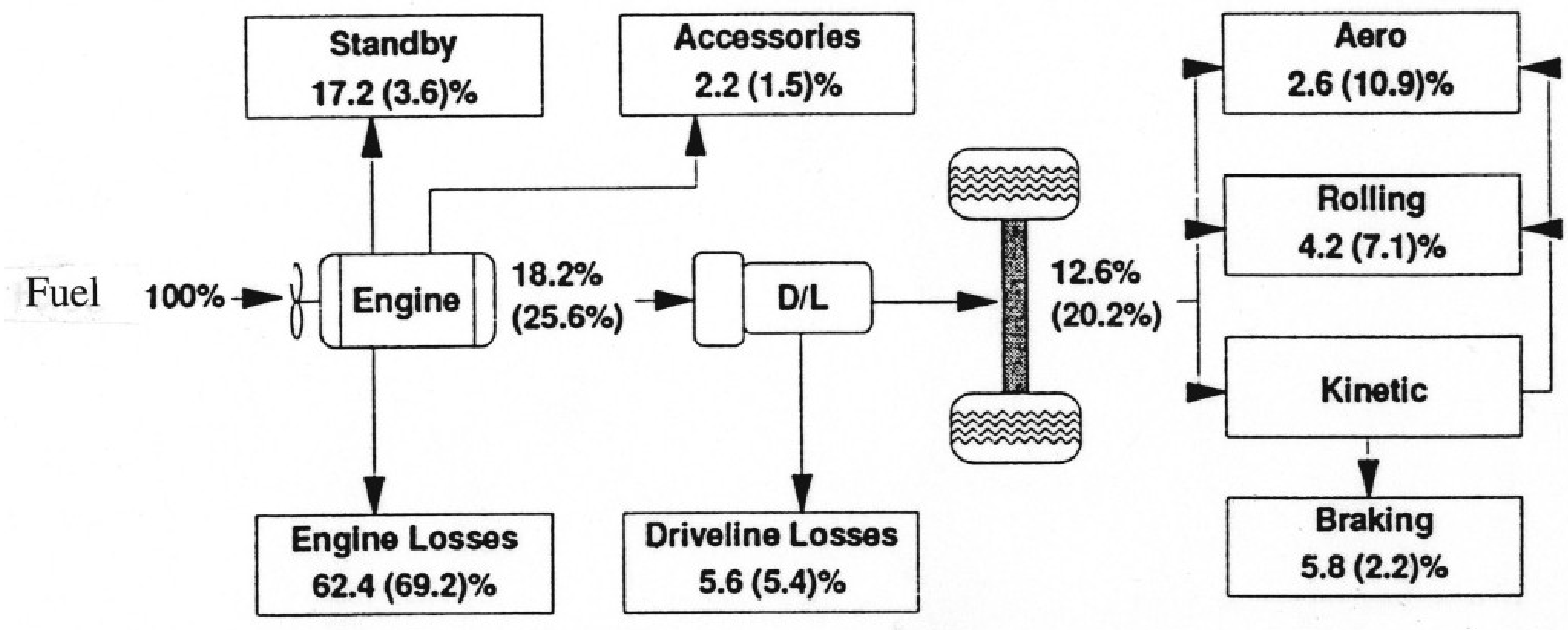
CO2 " Well - to - Wheel " Analysis



Source (CO2): European Council for Automotive R&D (EUCAR) – assuming 12,000 km per year usage

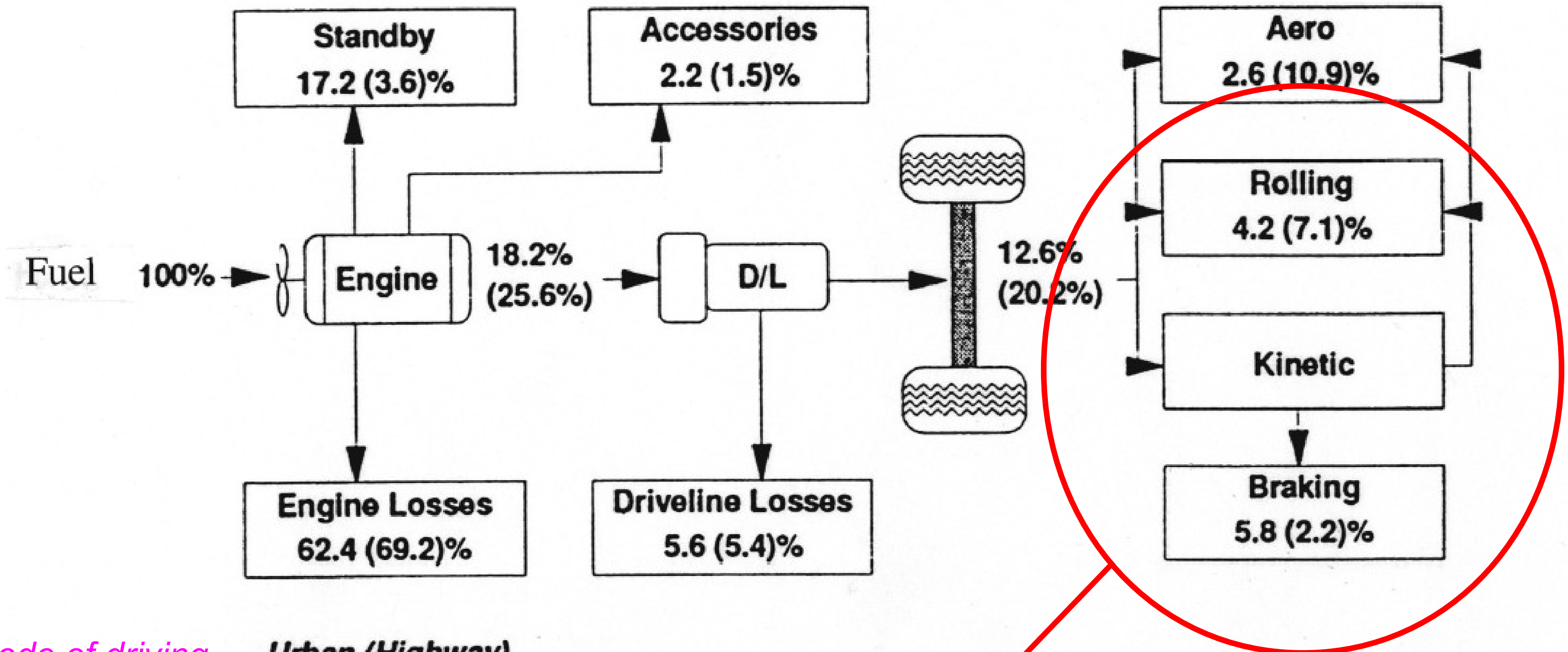
Energy Distribution in a mid-size Car



Mode of driving … ***Urban (Highway)***

Energy Distribution in a mid-size Car

Technology Improvement Area 1

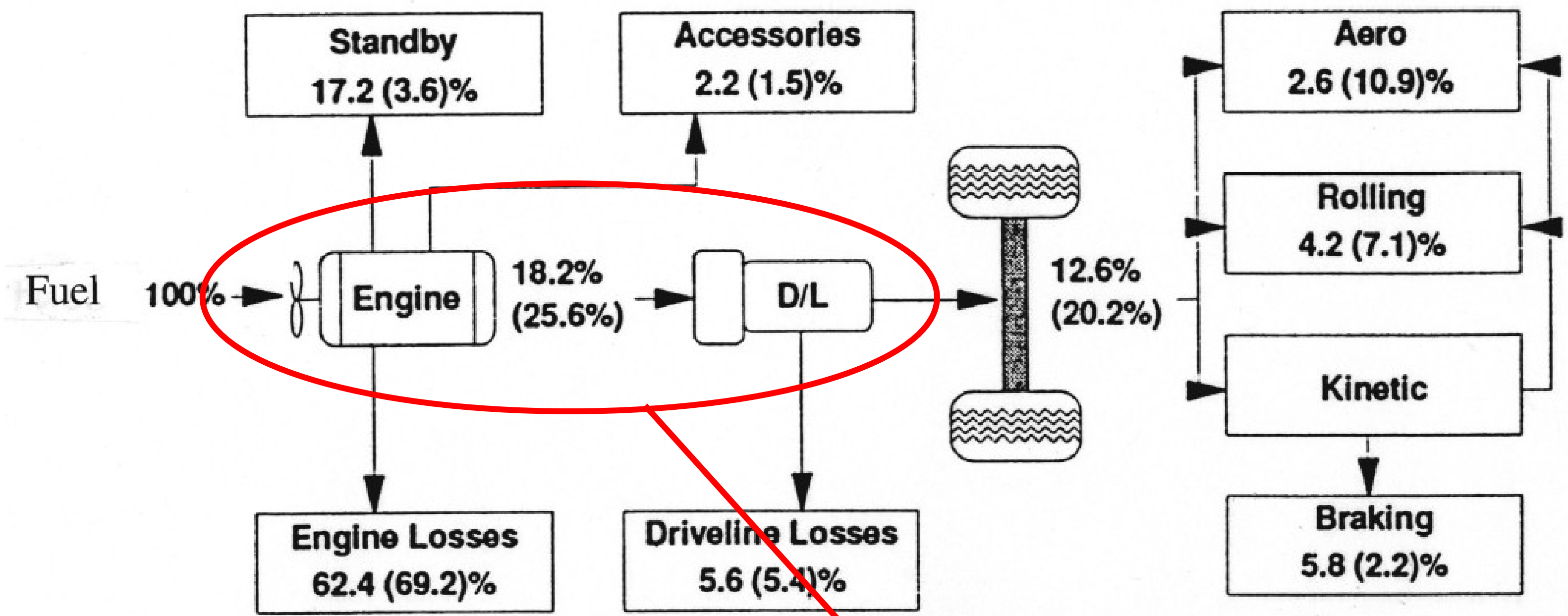


Mode of driving … ***Urban (Highway)***

Reduced vehicle weight proportionally less energy used

Energy Distribution in a mid-size Car

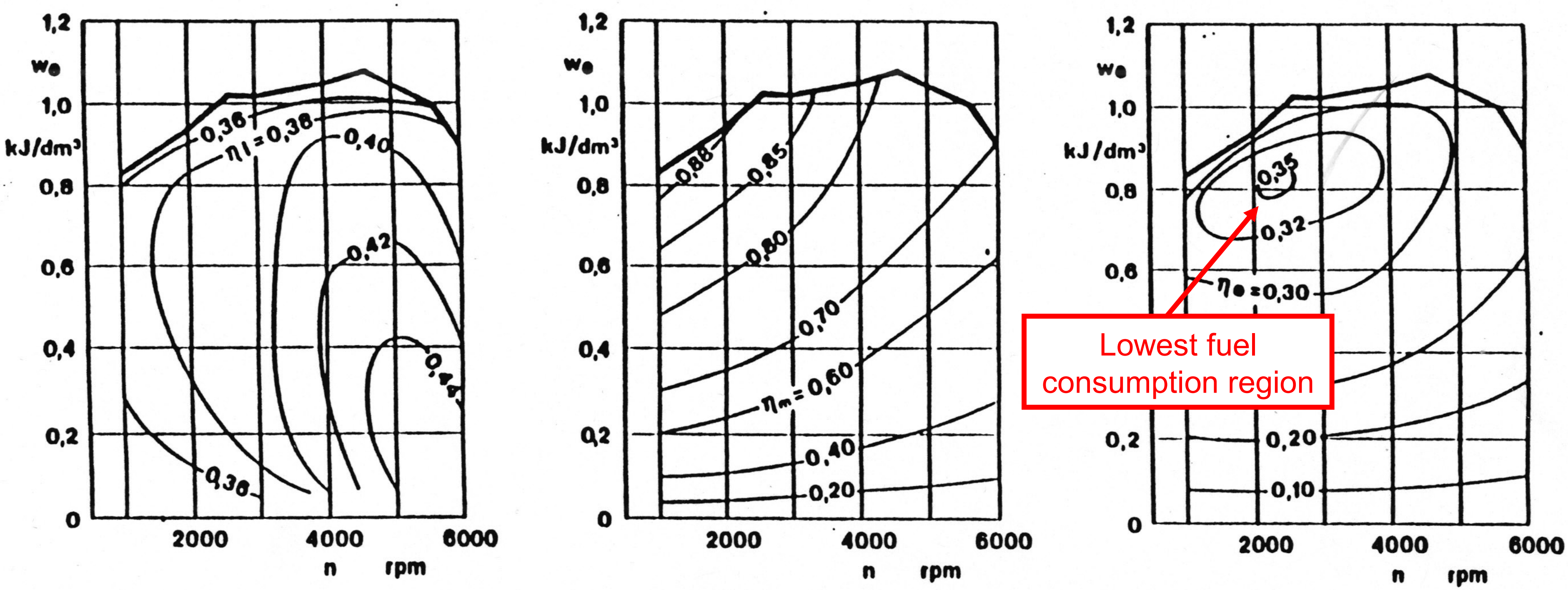
Technology Improvement Area 2



Mode of driving … ***Urban (Highway)***

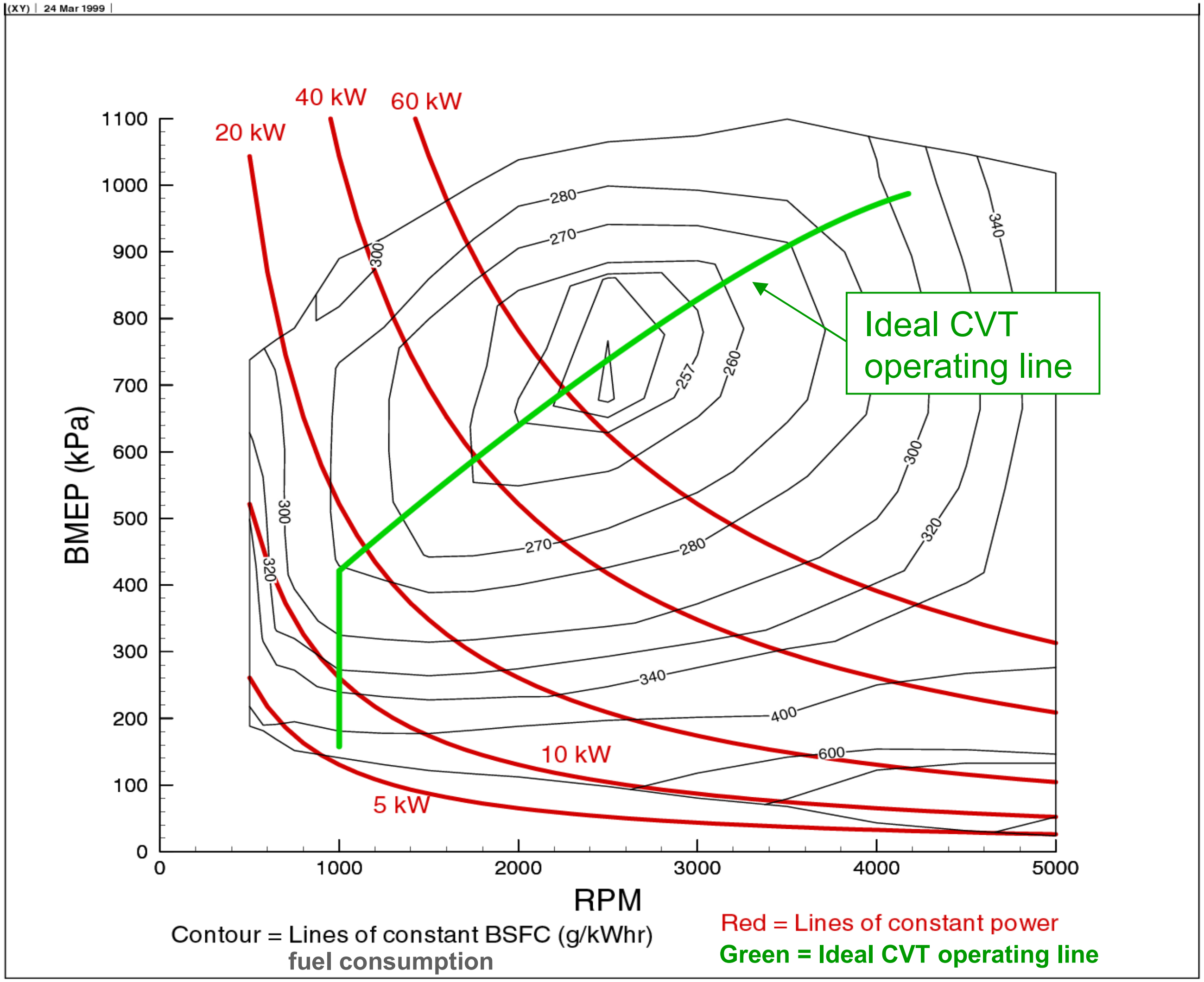
Continuously Variable Transmission CVT keep engine operating in lowest fuel region

Engine Speed-Load Operation Map
with efficiency contours



Indicated Efficiency In-cylinder x Mechanical Efficiency = Brake Efficiency at output shaft

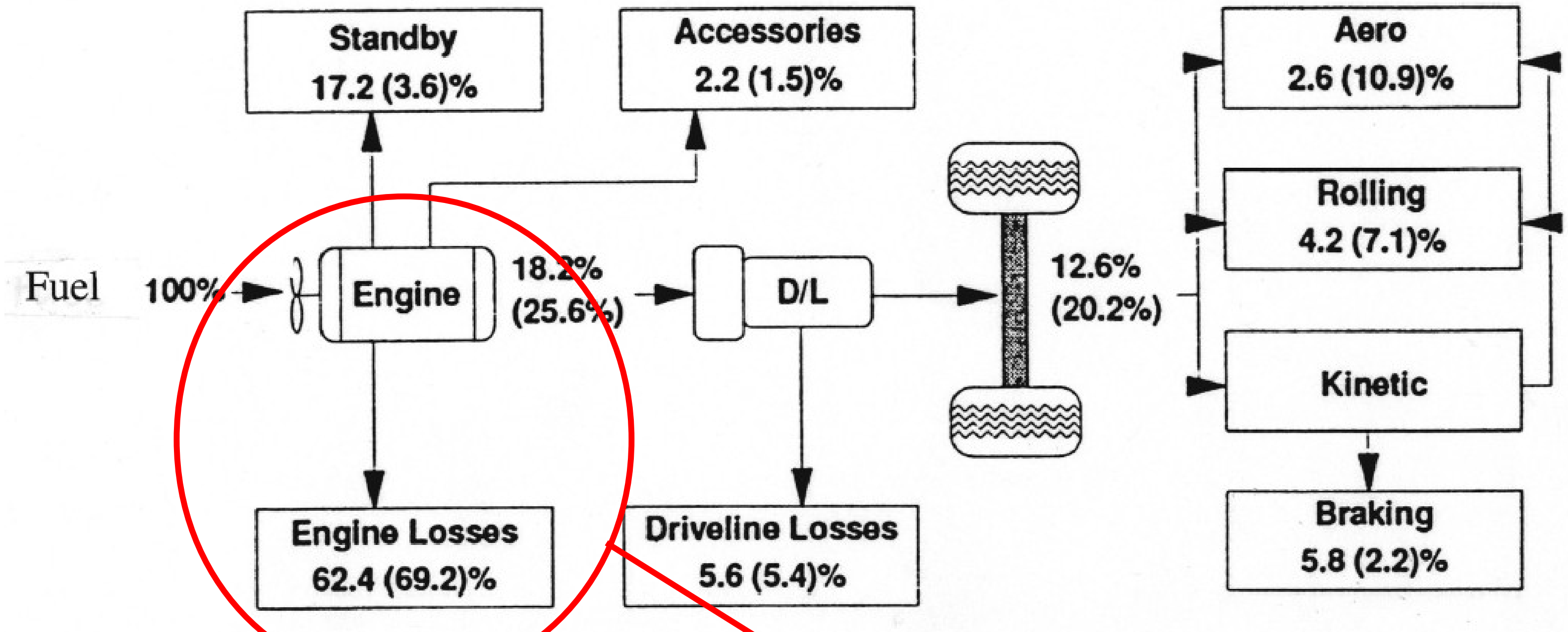
CVT Potential



Example: Cruise on 60 kW power line at CVT speed/load point
is more efficient than at other fixed-gear-ratio speed/load points

Energy Distribution in a mid-size Car

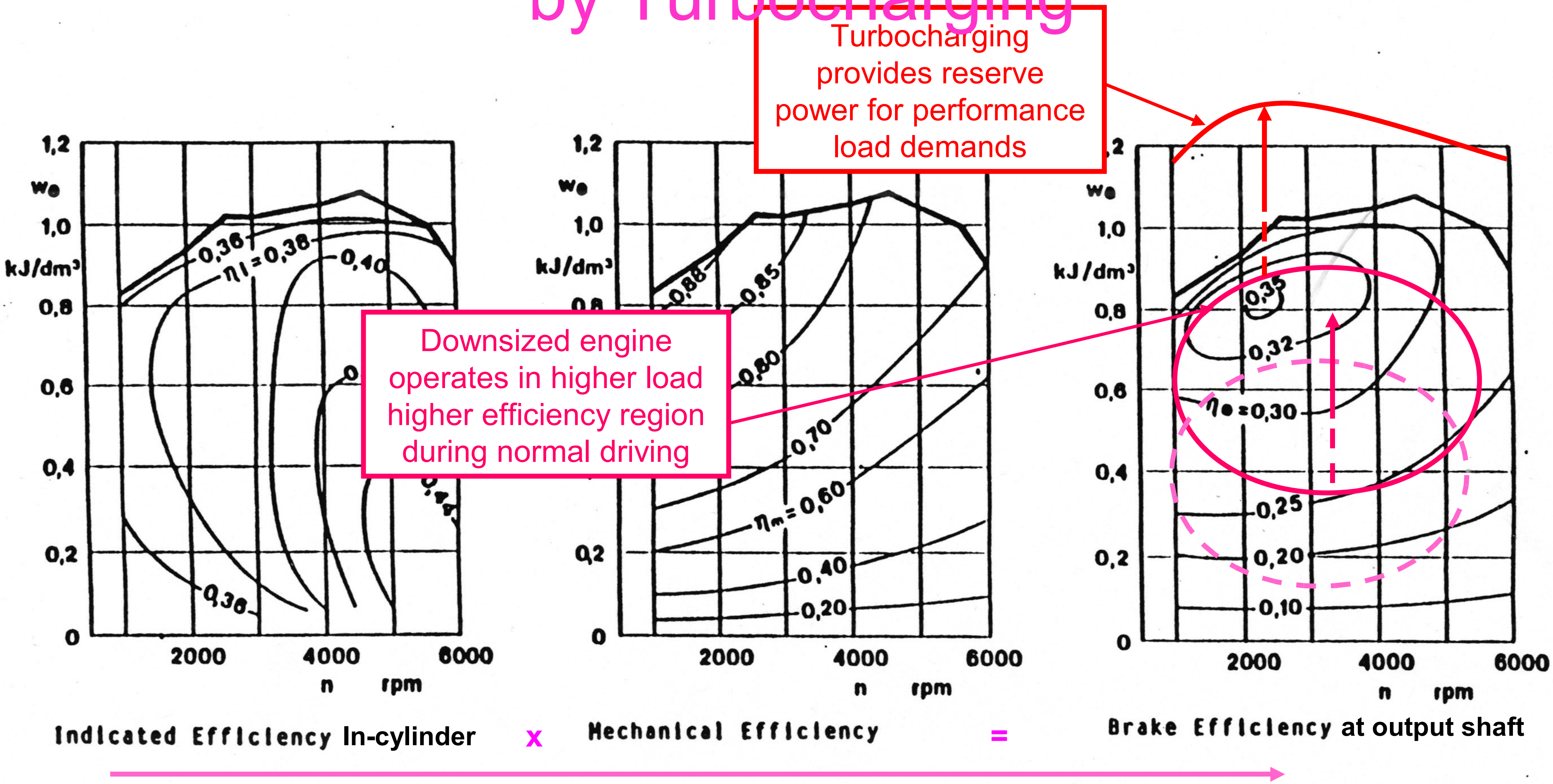
Technology Improvement Area 3



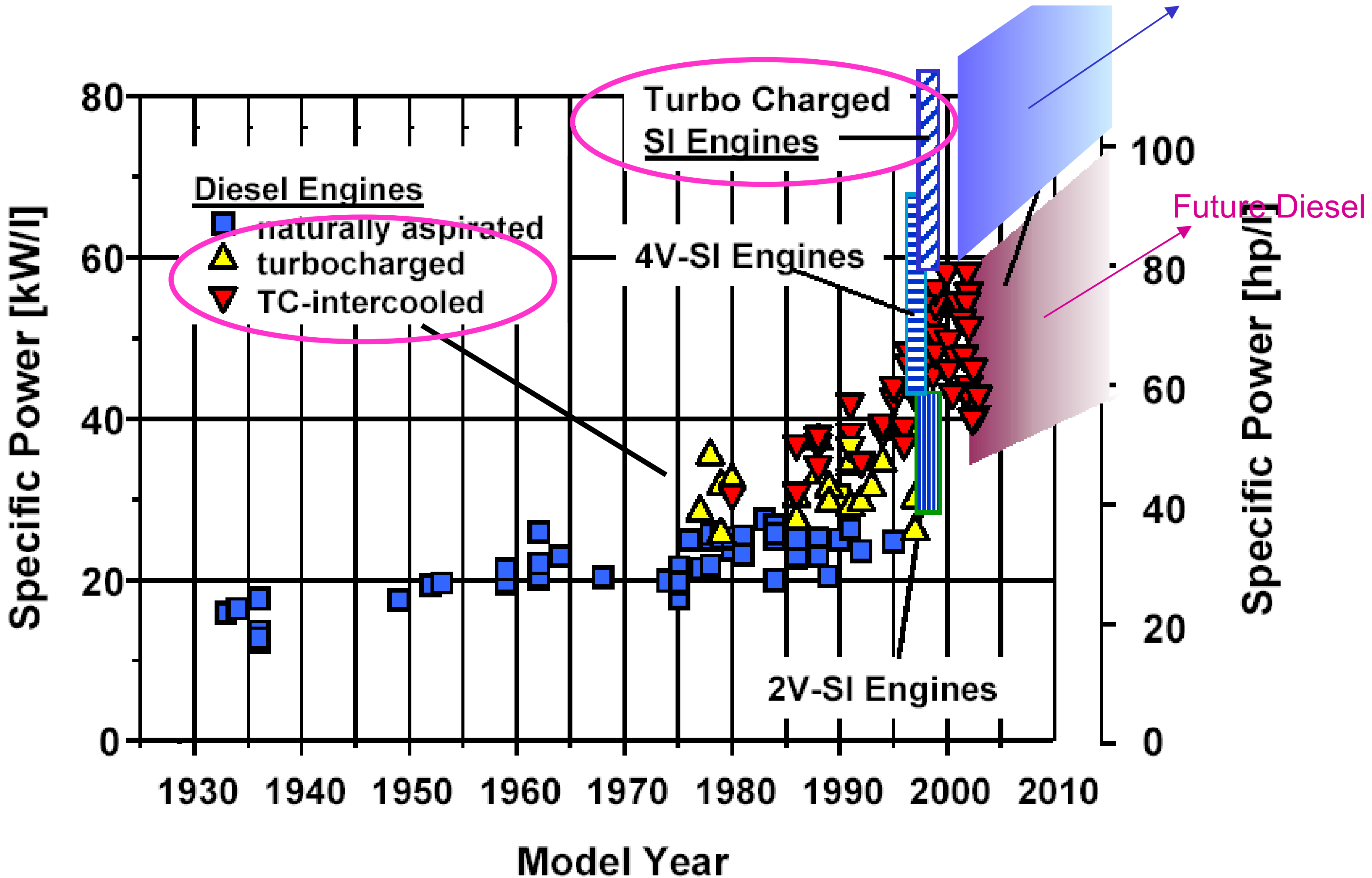
Mode of driving … ***Urban (Highway)***

Downsized high specific output engine proportionally less engine losses

Downsized High Specific Output Engine by Turbocharging

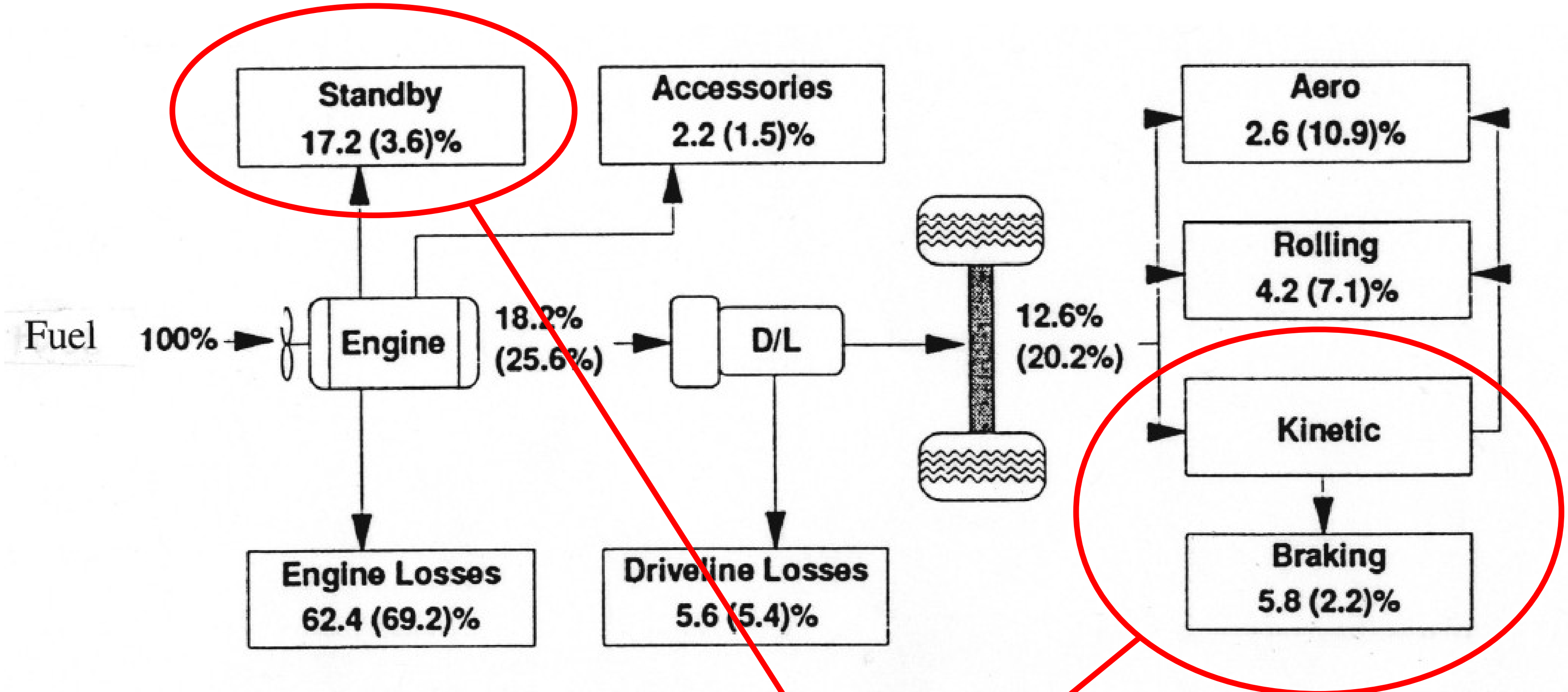


Downsized high specific output turbo-charged engines



Energy Distribution in a mid-size Car

Technology Improvement Area 4

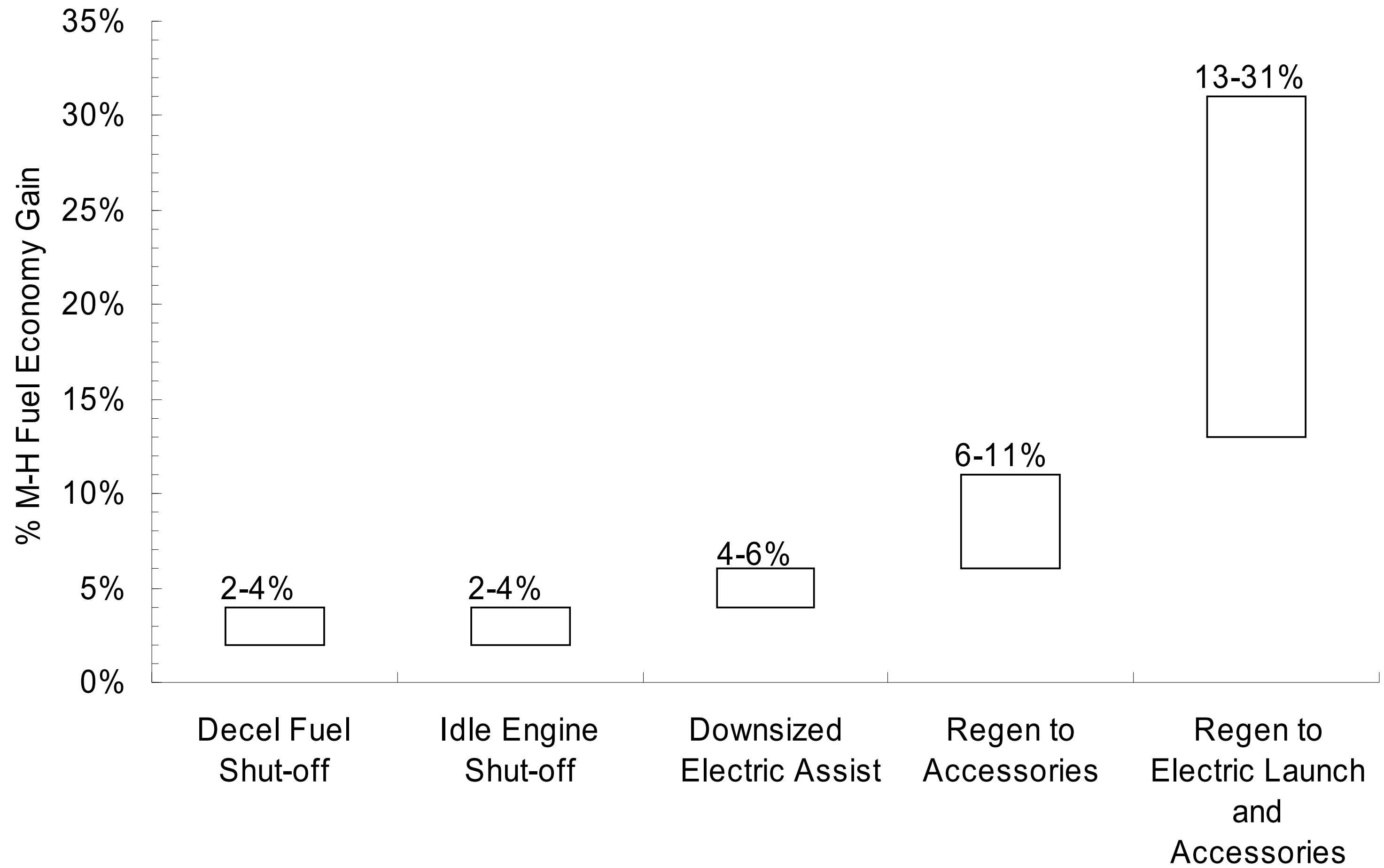


Mode of driving … ***Urban (Highway)***

Hybrid vehicles

idle engine shut-off, regenerative braking

Hybrid Electric Powertrain Fuel Economy Benefit



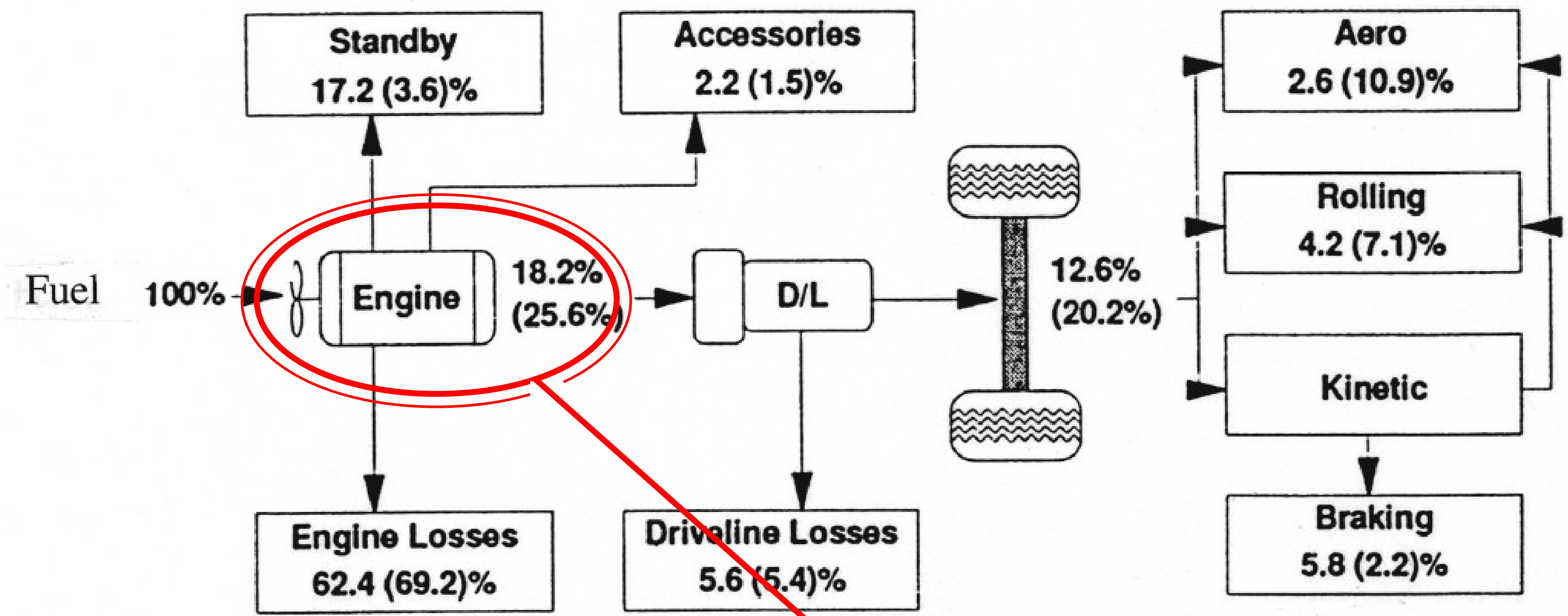
Hybrid Electric Powertrain Architecture

The Hybrid Electric System seeks to operate the combustion engine at maximum efficiency, or shut it off

- Function 1 - Engine stop-start
- Function 2 - KE recovery and regeneration
- Function 3 - Motor assist
- Function 4 - EV drive

Energy Distribution in a mid-size Car

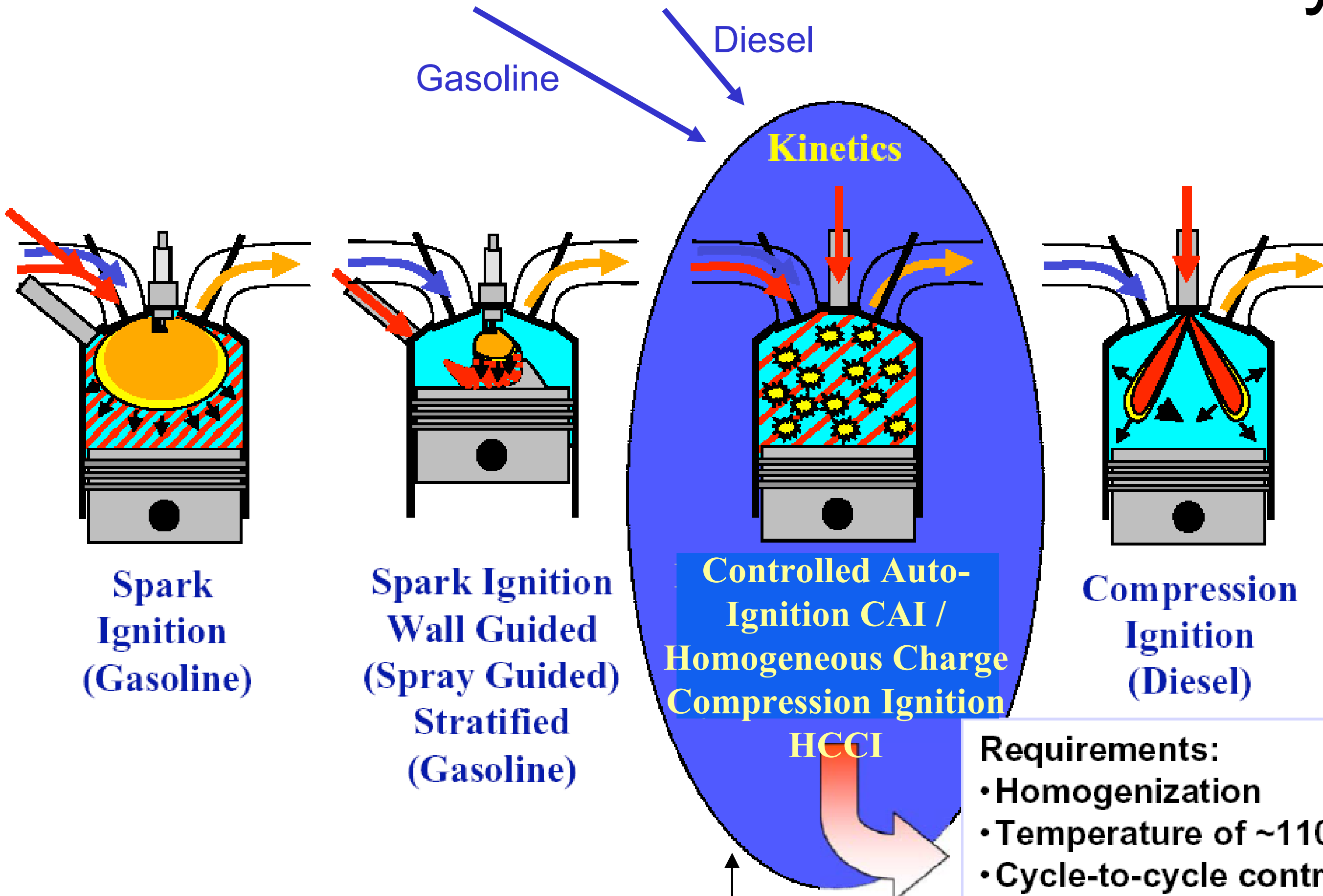
Technology Improvement Area 5



Mode of driving … ***Urban (Highway)***

Advanced Combustion Engines CAI / HCCI
high efficiency, ultra-low NOx
emissions

Preview of CAI / HCCI Combustion System

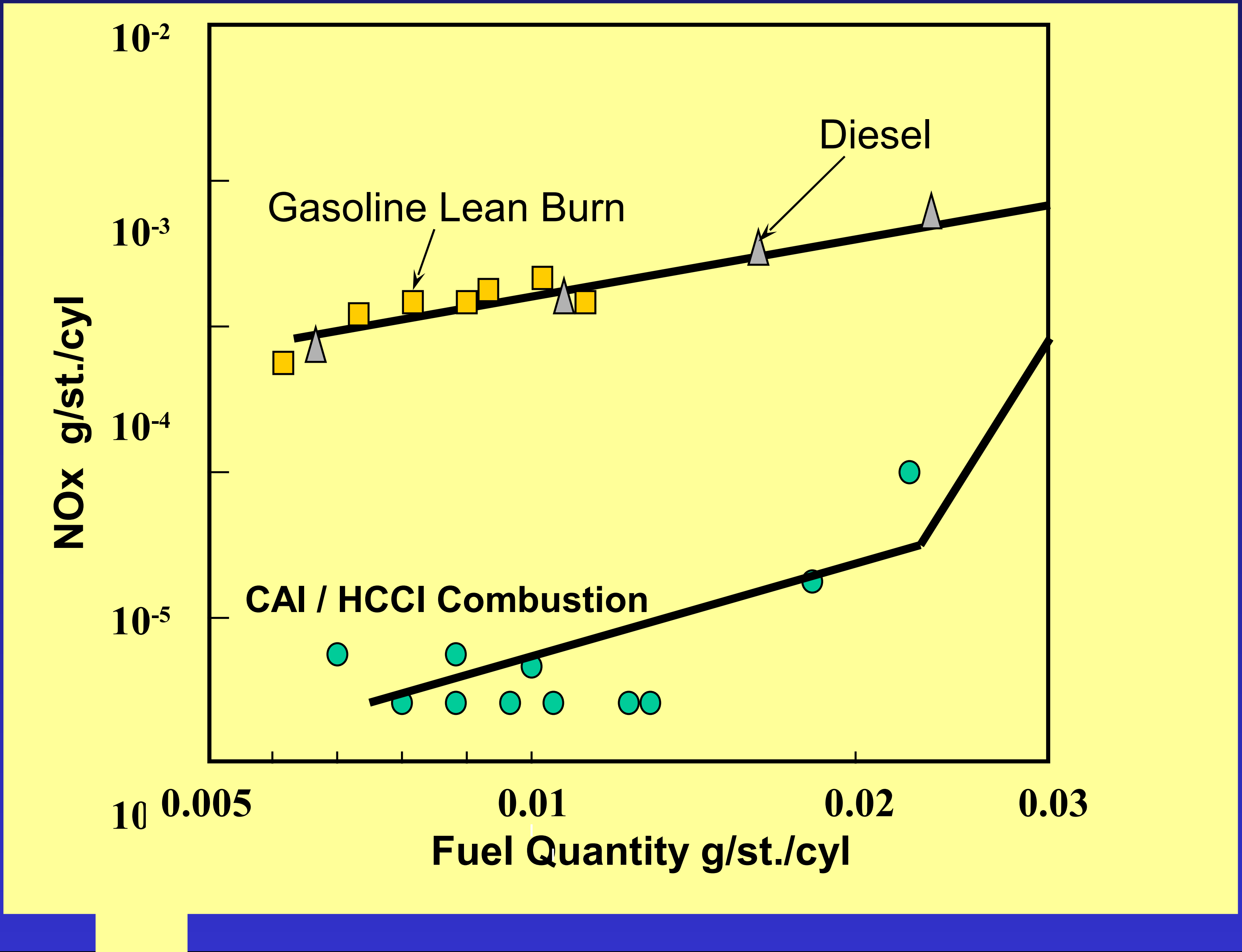


Requirements:
- **Homogenization**
- **Temperature of ~1100 K**
- **Cycle-to-cycle control parameter**

Multi-ignition sites low temperature combustion avoid soot and NOx formation

Key technology: EGR dilution

CAI / HCCI NOx Emissions



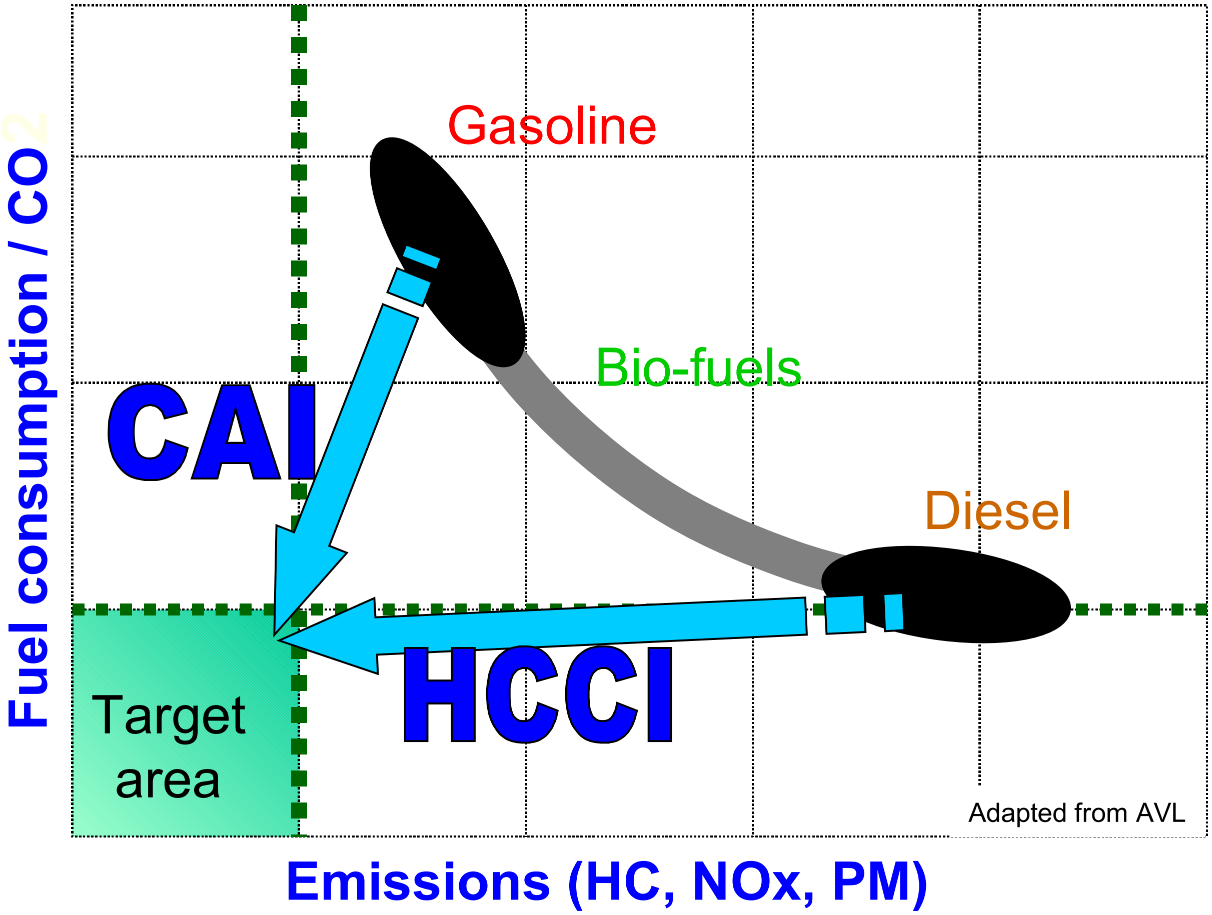
IC Engines: the new challenge

Gasoline engine

- CO_2
- NOx

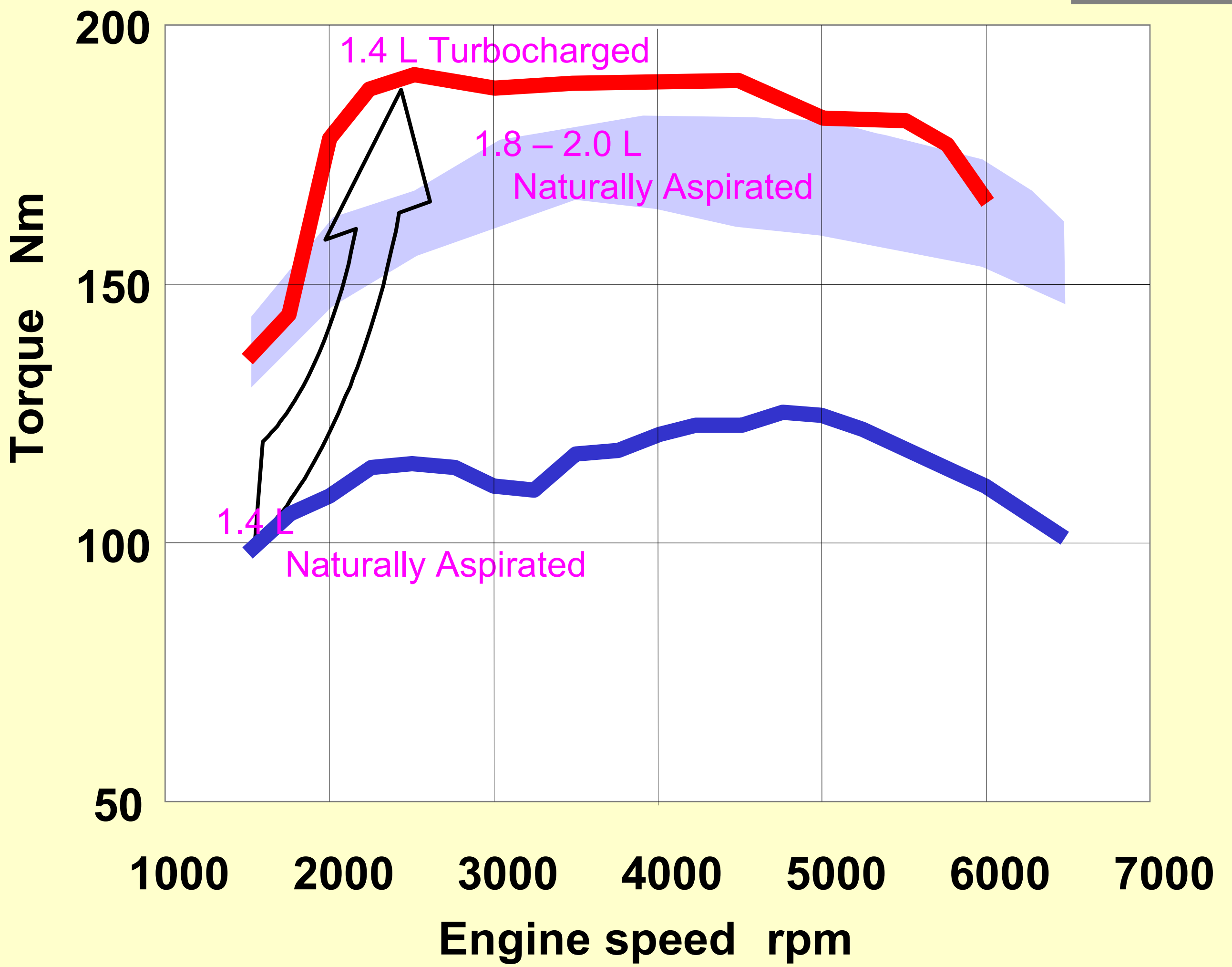
Diesel engine

- PM
- NOx

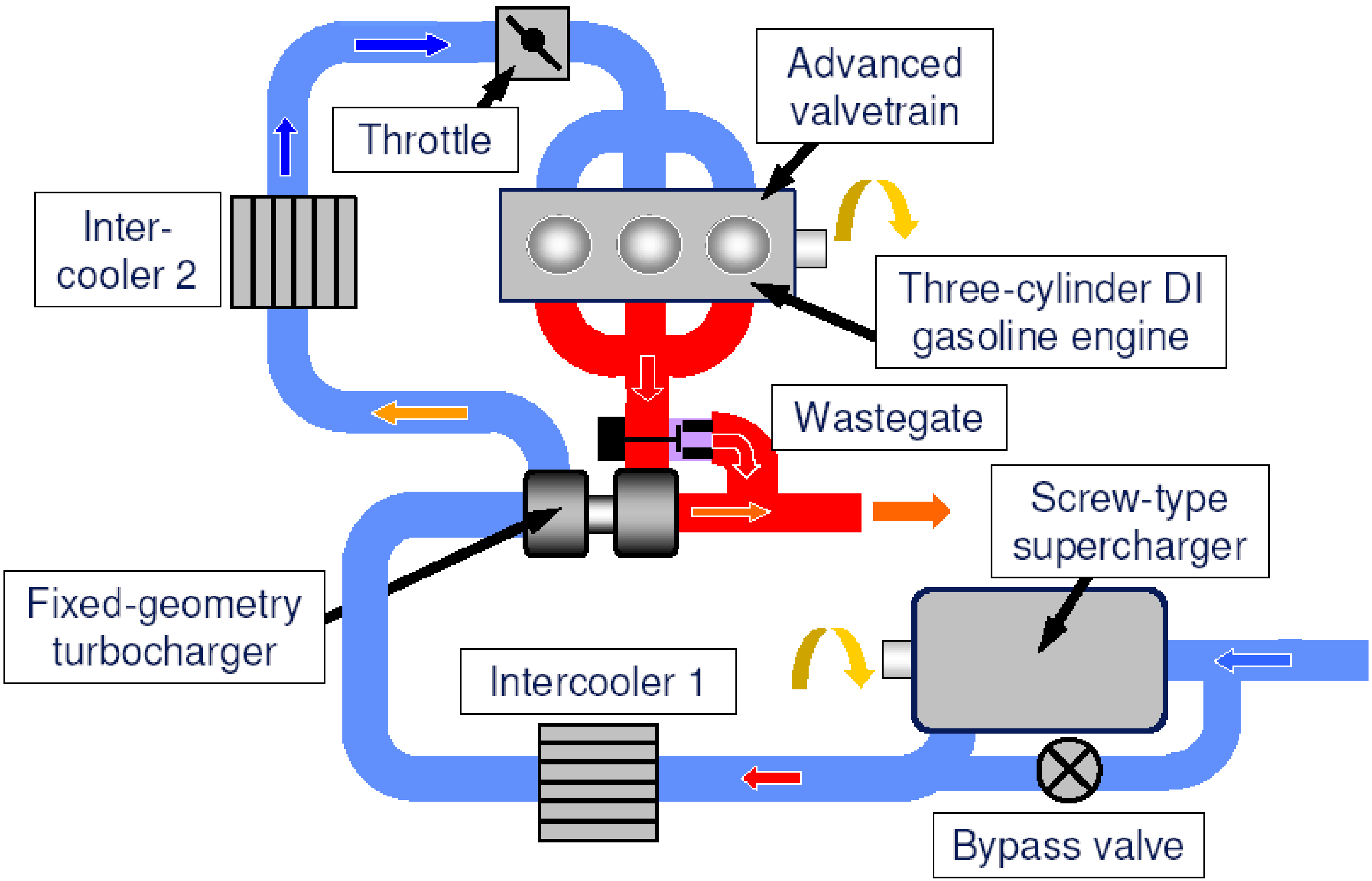


FUEL ECONOMY AND FUN-TO-DRIVE

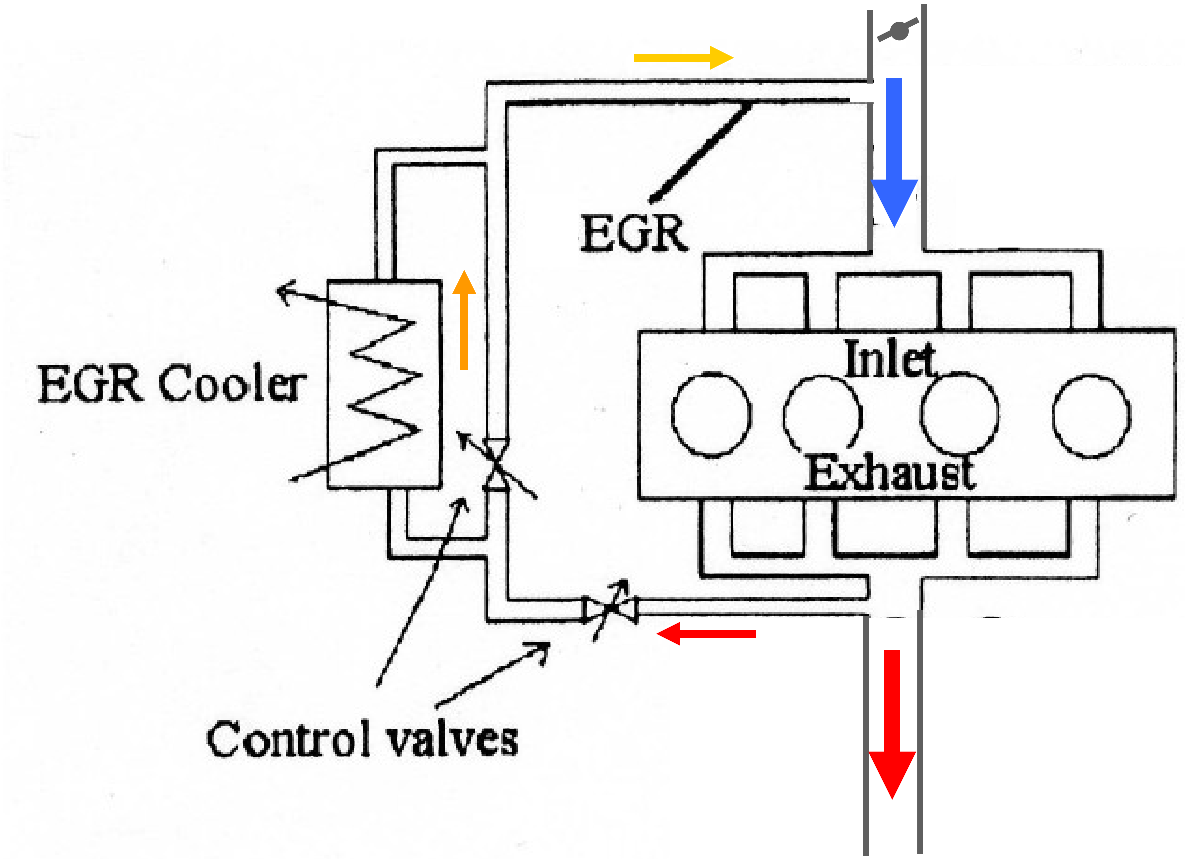
DOWNSIZING



Downsized Engine with Turbocharger and/or Supercharger



Source: Ricardo

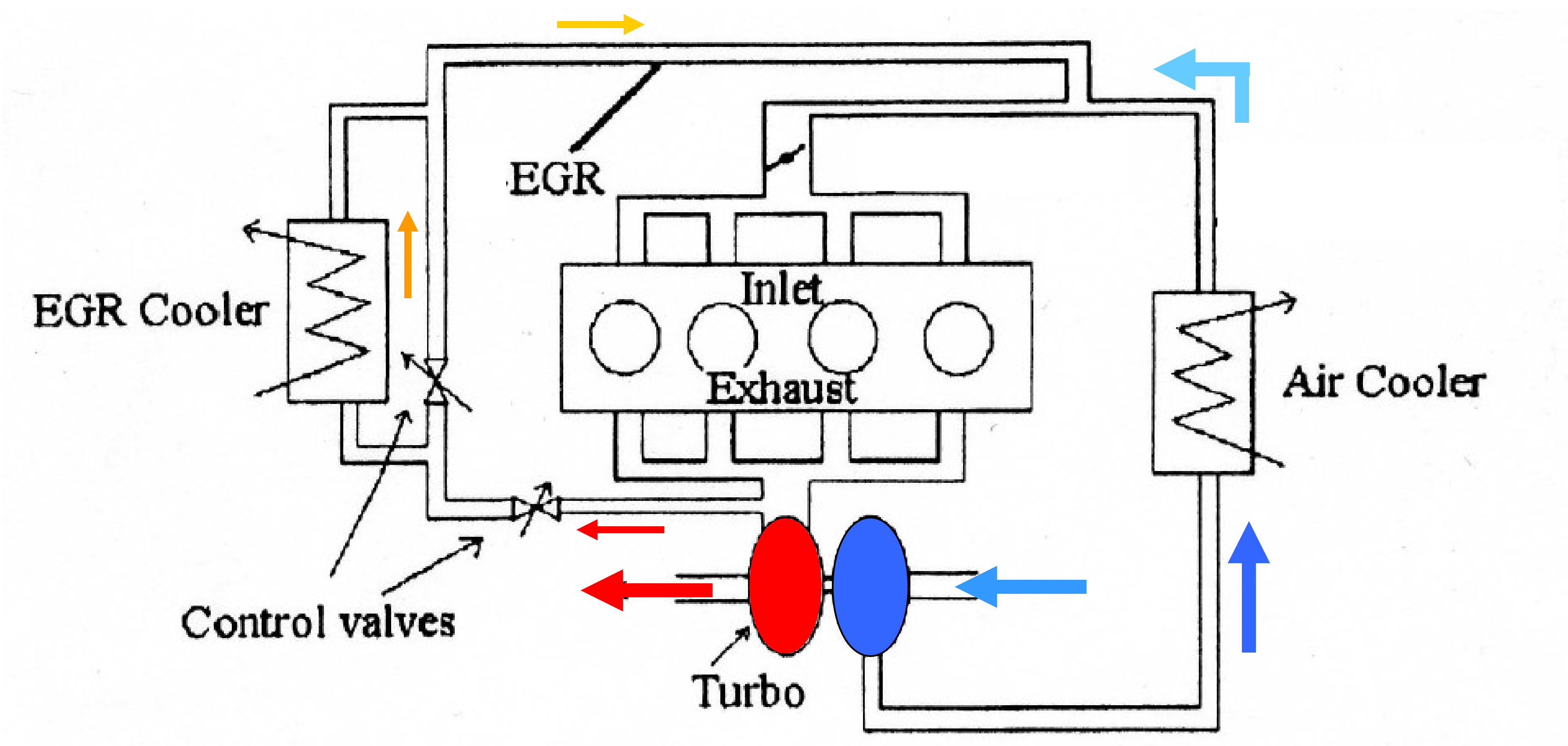


Function

- **Reduce the oxygen content in the combustible charge**
- **Lower the combustion temperature, avoid formation of NOx**
- **Key technology in CAI/HCCI combustion engines**
- **More effective with cooled EGR**

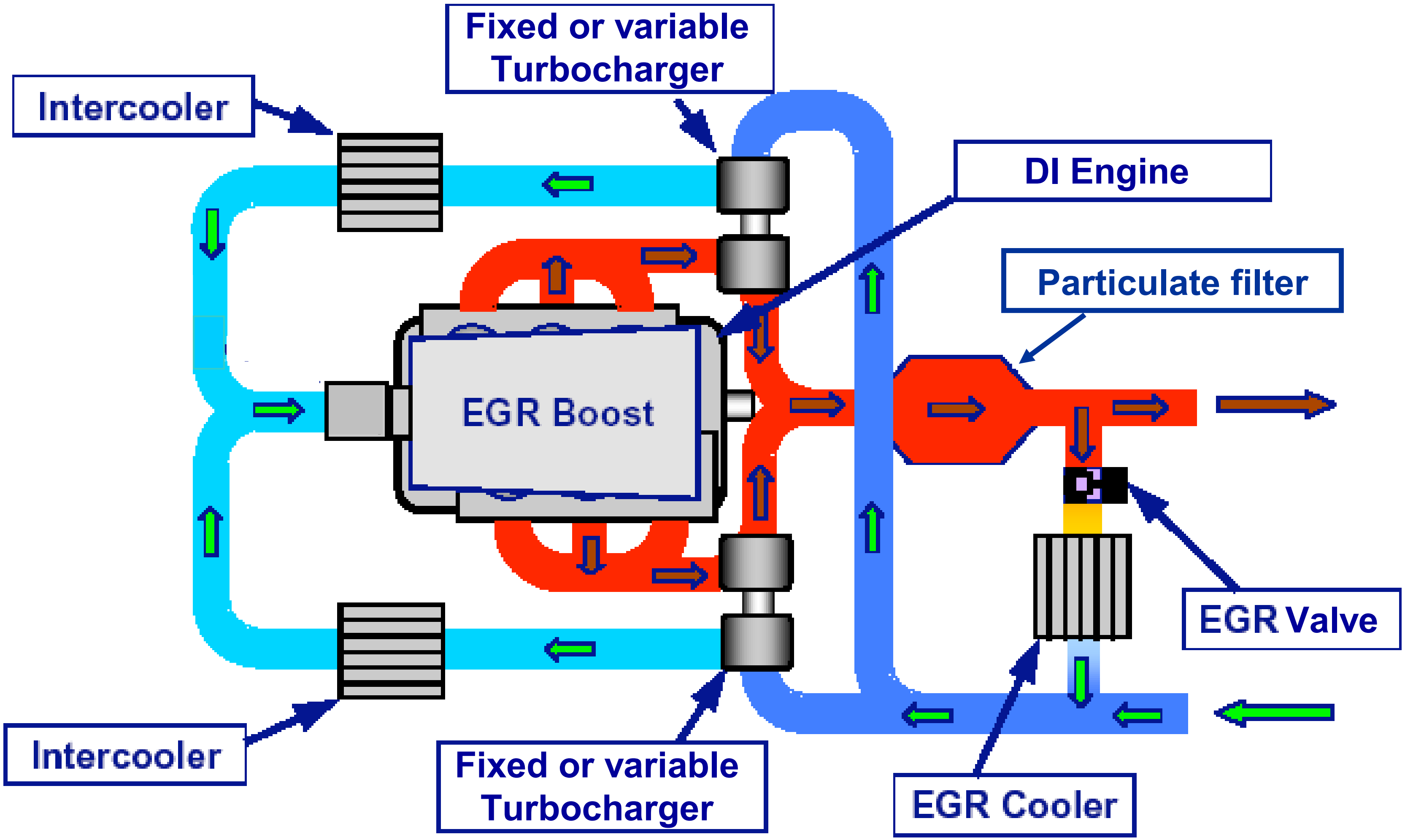
Exhaust Gas Recirculation EGR System for Reduction of NOx Emissions

This is Essential



High Pressure
Turbocharged engine layout (with EGR system).
Duchaussoy et al. (Renault) SAE 2003-01-0629

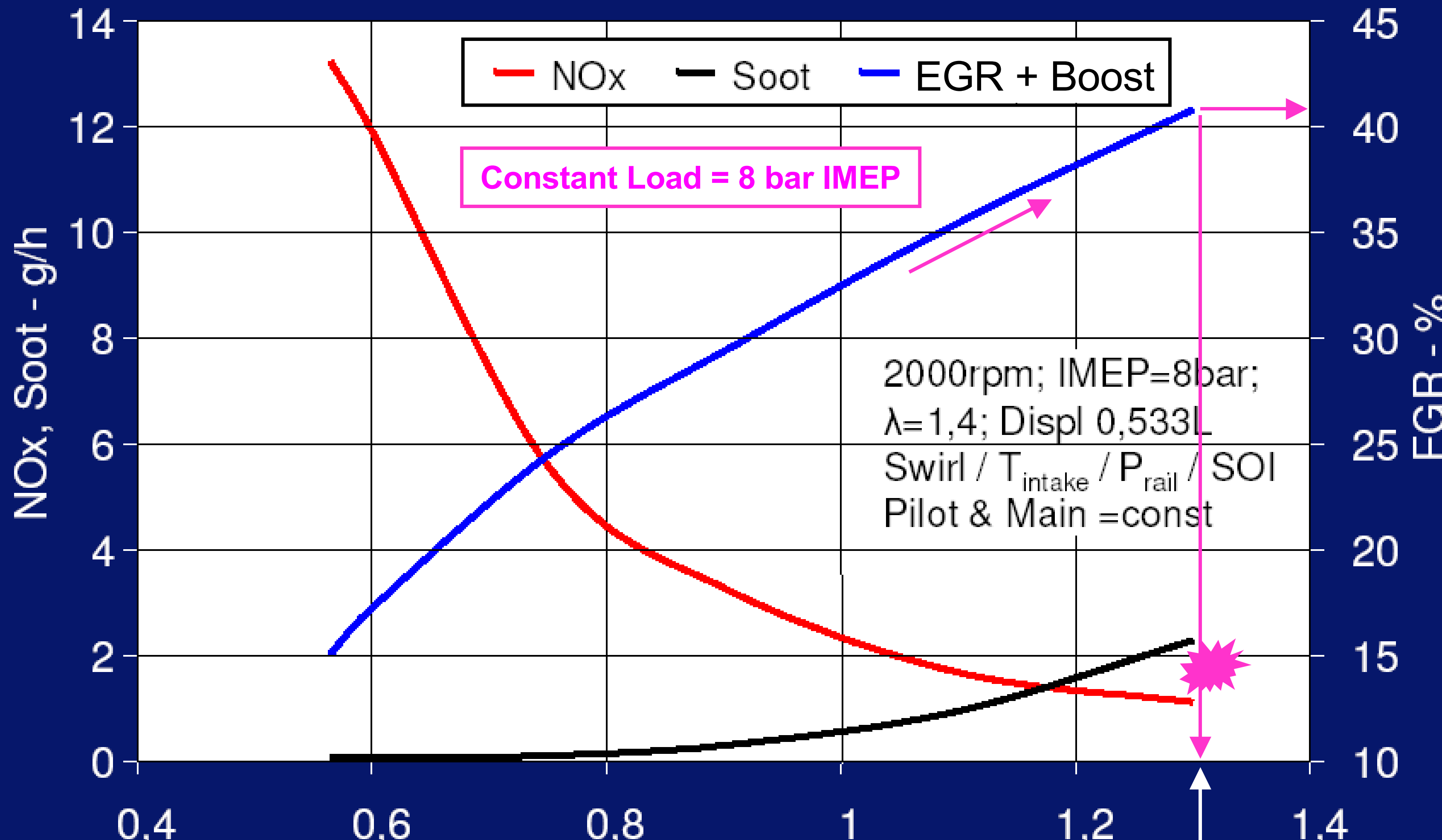
Turbocharged Engine with Low Pressure EGR System



Source: Ricardo

Reducing NOx and Soot emissions with High EGR and High Boost

AVL



*) SCRE: single cylinder research engine

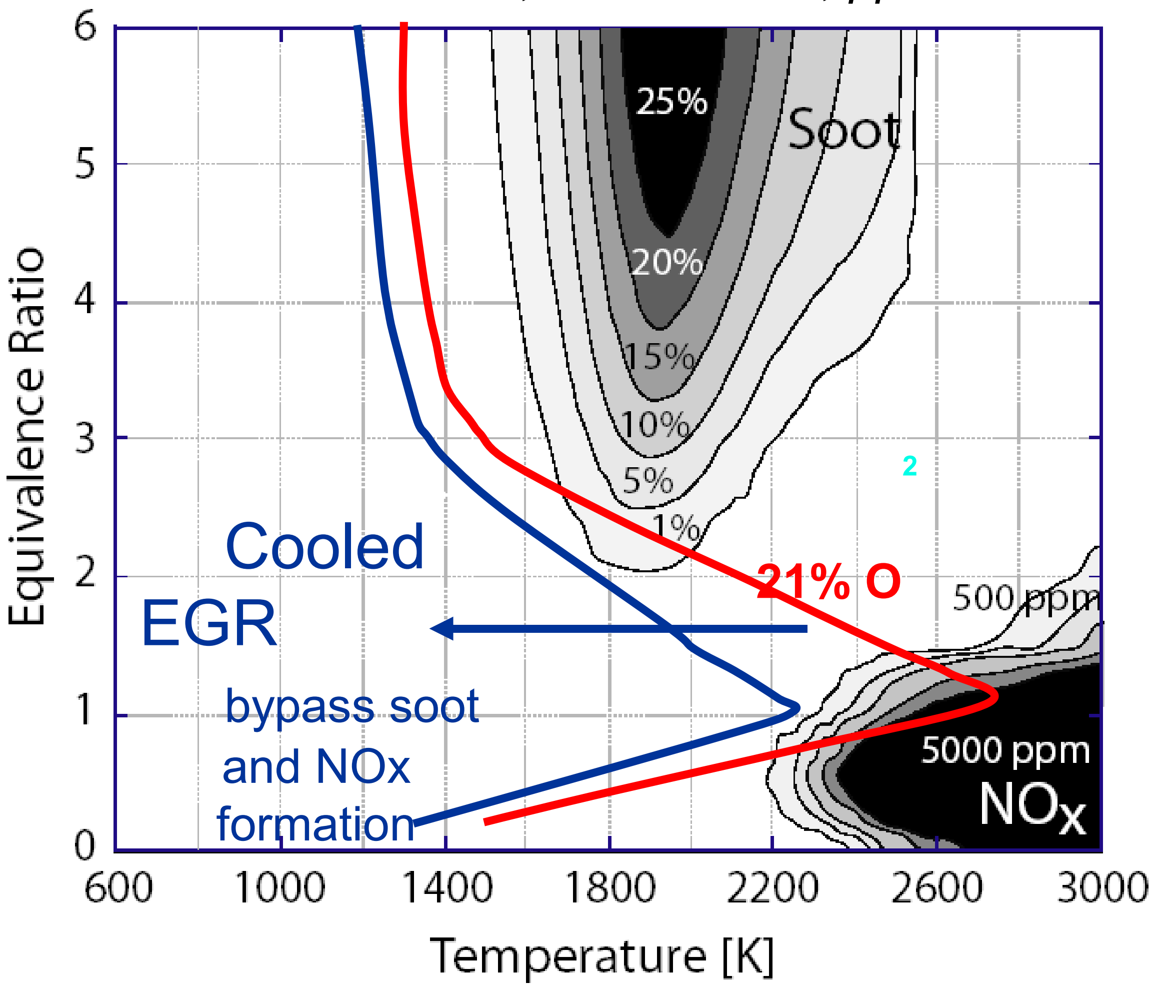
(Singe Cylinder Engine artificially boosted)

Challenge

- Today's demand for high rate of EGR (40%+) and high Boost at the same time (technology gap)
- Conventional HP system requires high Δp to force the high% EGR against high boost pressure
- High% EGR will divert the same% of engine exhaust energy away from the turbocharger
- Alternative LP system takes EGR from turbine exit of turbocharger and with necessary Δp
- Then the EGR must go into the blower entry and both EGR & air must be boosted (bigger blower)
- In both systems, EGR and Boost work awkwardly in uneasy partnership (need technology jump)

Diesel HCCI / LTC Combustion with Boost and Cooled EGR

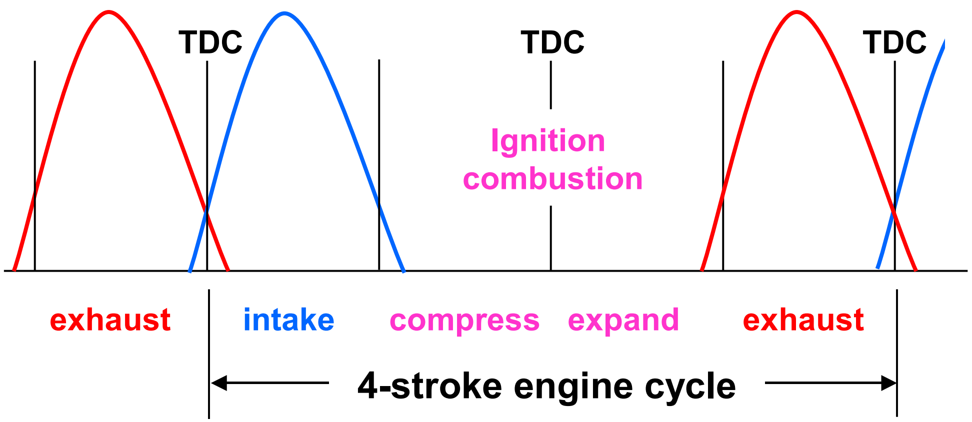
Source: Miles et al., Thiesel 2004, pp. 429-447

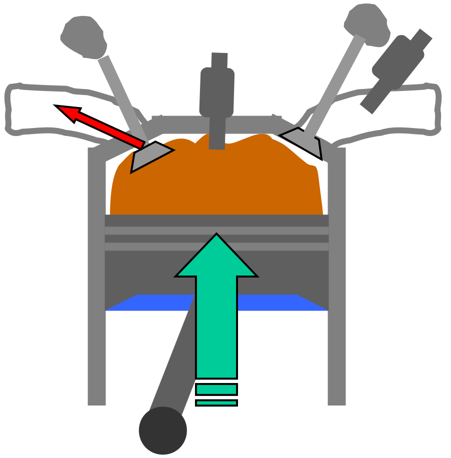


A major driver for developing Variable Engine Valvetrain is to achieve high rate of EGR with or without boost by internal gas retention means (internal EGR) to supplement or replace external EGR

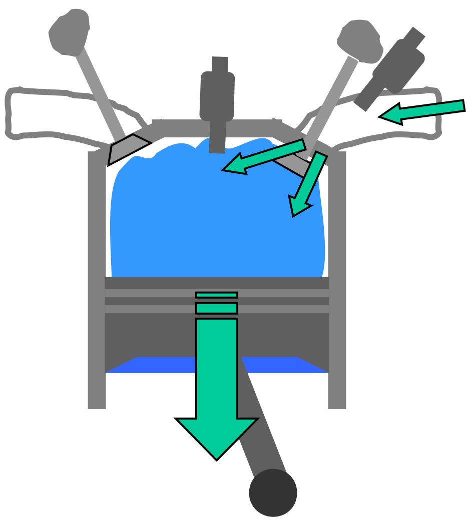
Note: Small amount of residual gases is always present in conventional engines

Fixed or Variable Valve Lift Profiles



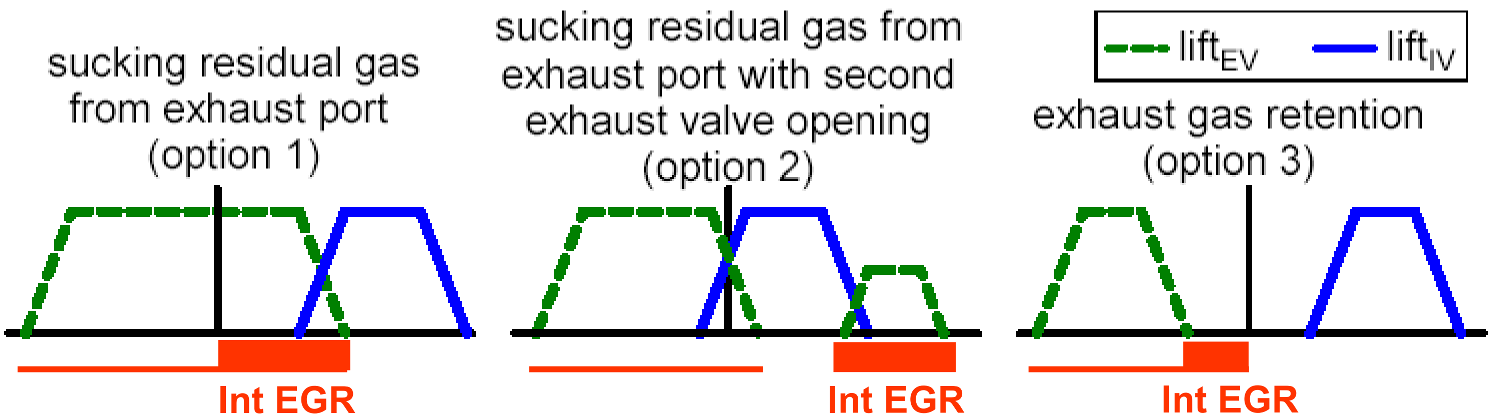


Exhaust Stroke



Intake Stroke

Variable Valve Control methods for Internal EGR by variable interaction between exhaust and intake valves, each valve independently controlled in lift duration and phasing

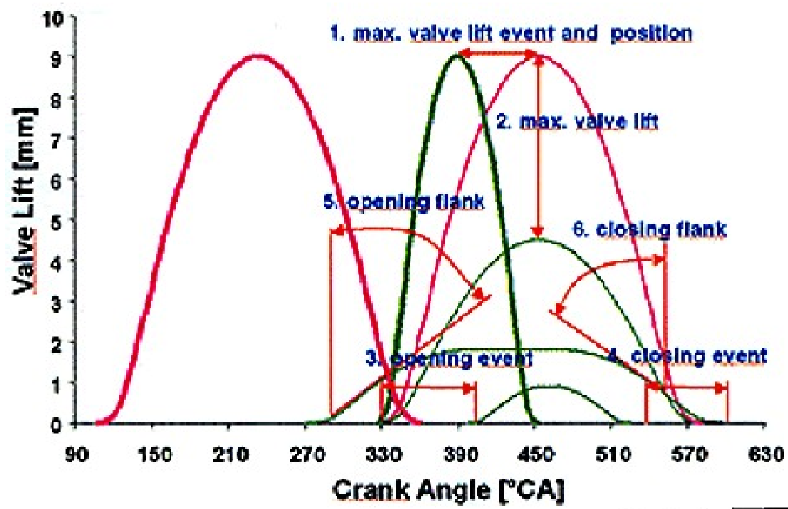


exhaust re-breathing 1
late exhaust closing
positive valve overlap
risk interference of exhaust valve with piston near TDC

exhaust re-breathing 2
exhaust valve re-open

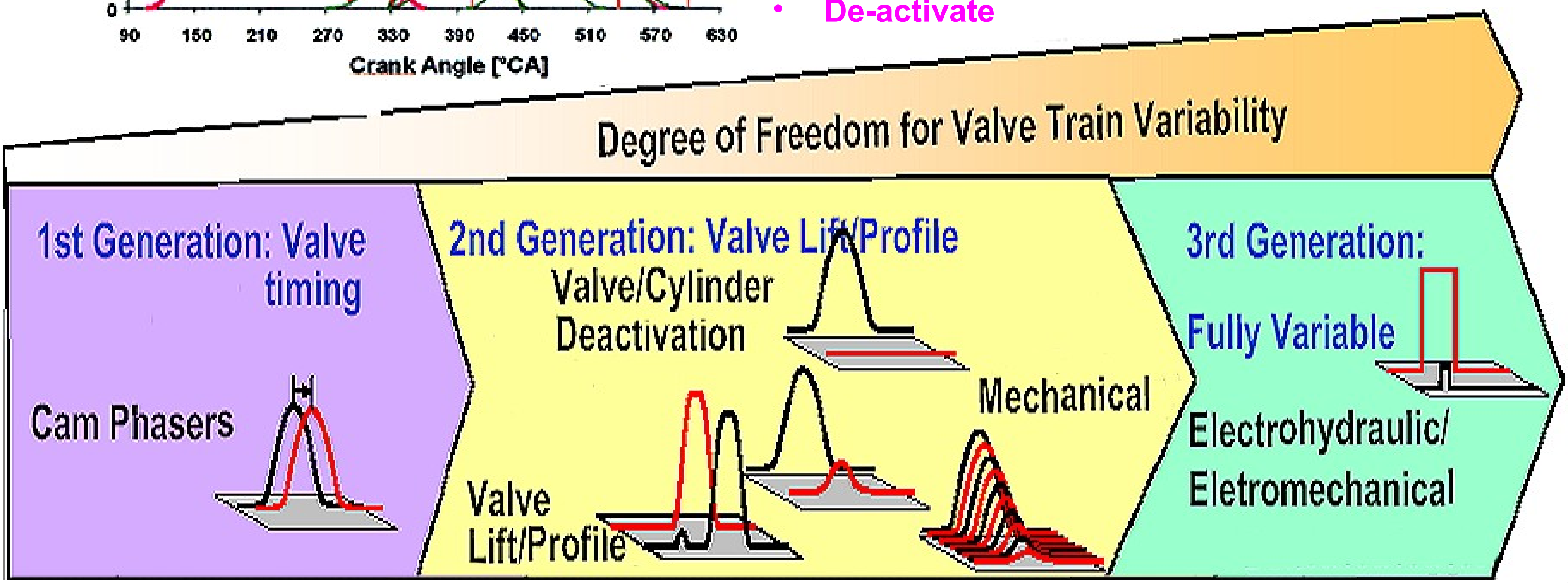
residual gas trapping
early exhaust closing negative valve overlap

Evolution of Variable Valve Train Capabilities



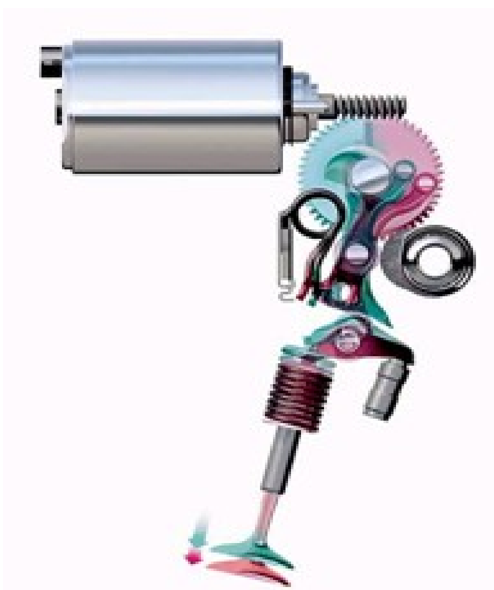
Exhaust and Intake Valves each independently variable:

- Lift - tall or short
- Profile - wide or narrow
- Phase - advance or retard
- Opening event - early and late
- Closing event - early or late
- De-activate

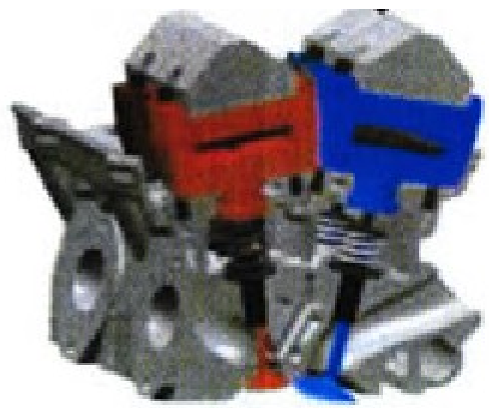


Variable Valve Actuation Systems

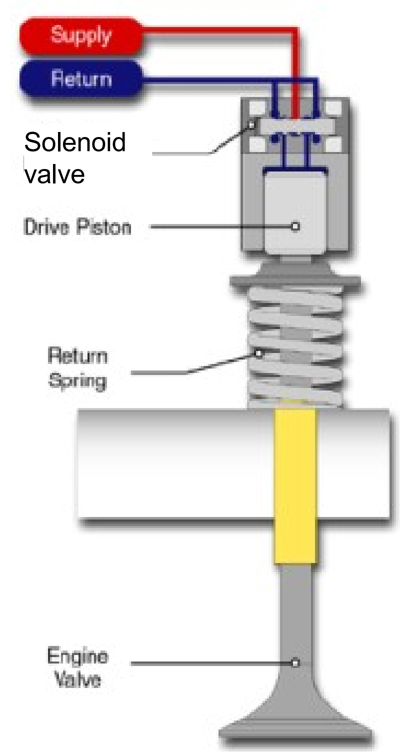
Mechanical cam driven



Electro-Mechanical camless

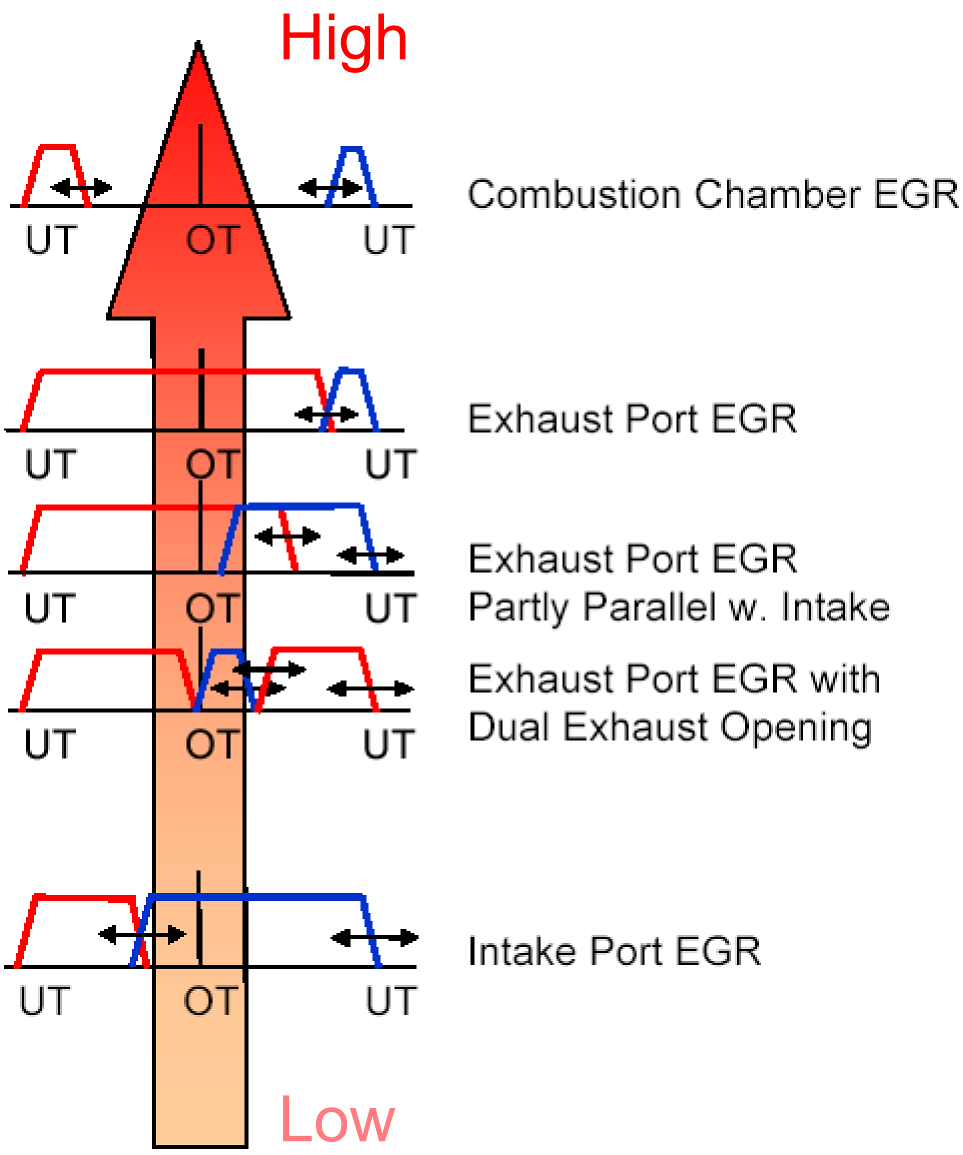


Electro-Hydraulic camless

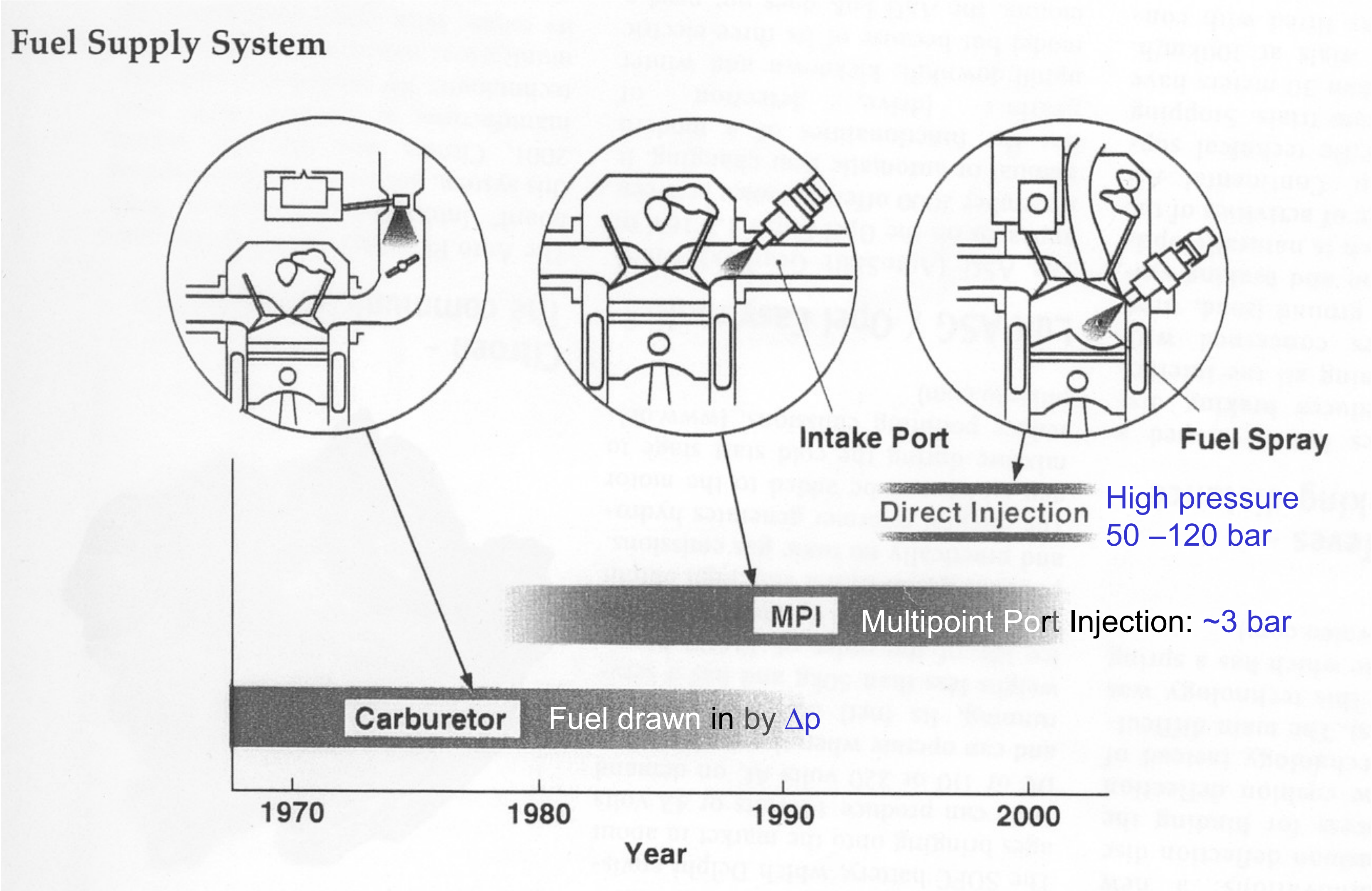


Internal EGR Temperature

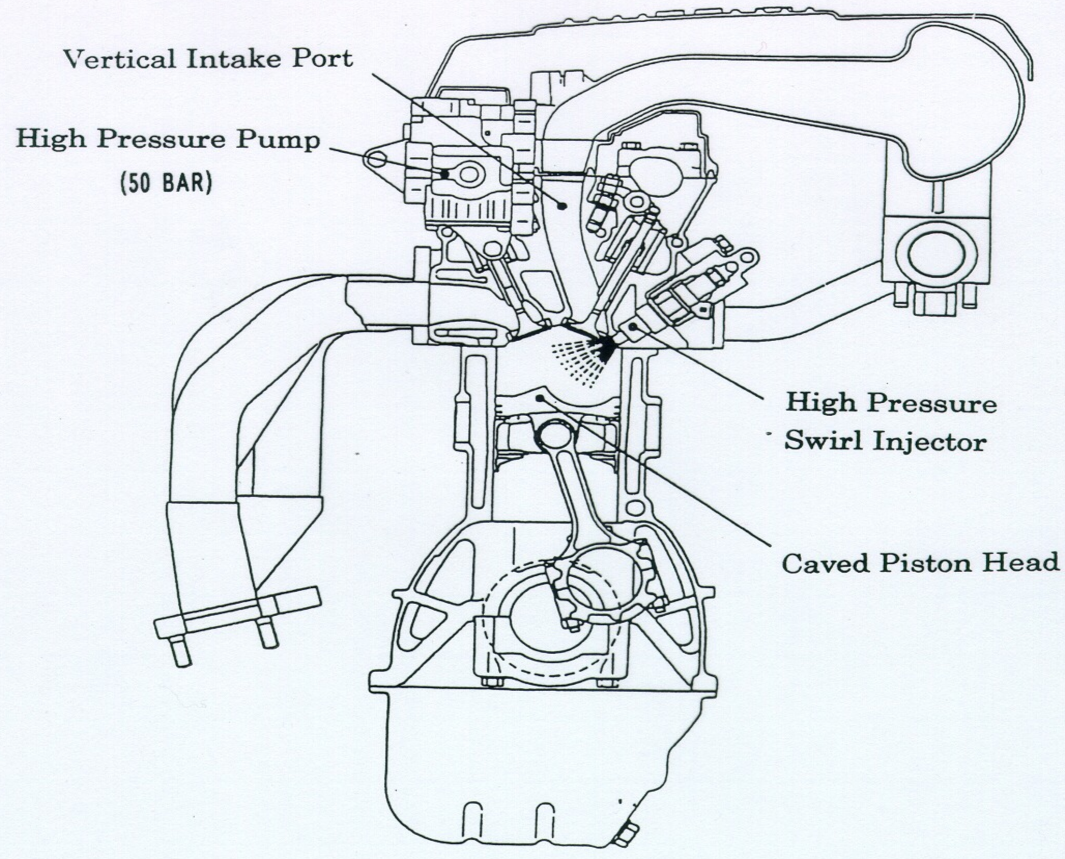
for different Variable Valve Control EGR Strategies



Evolution of Gasoline fuelling systems

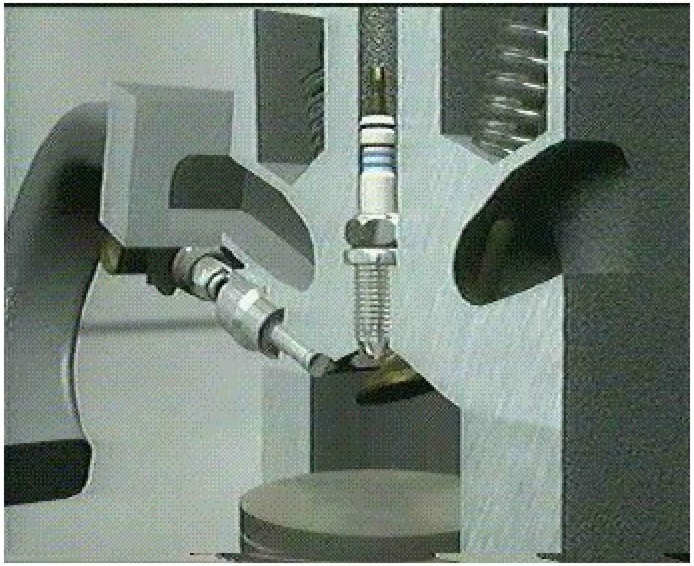


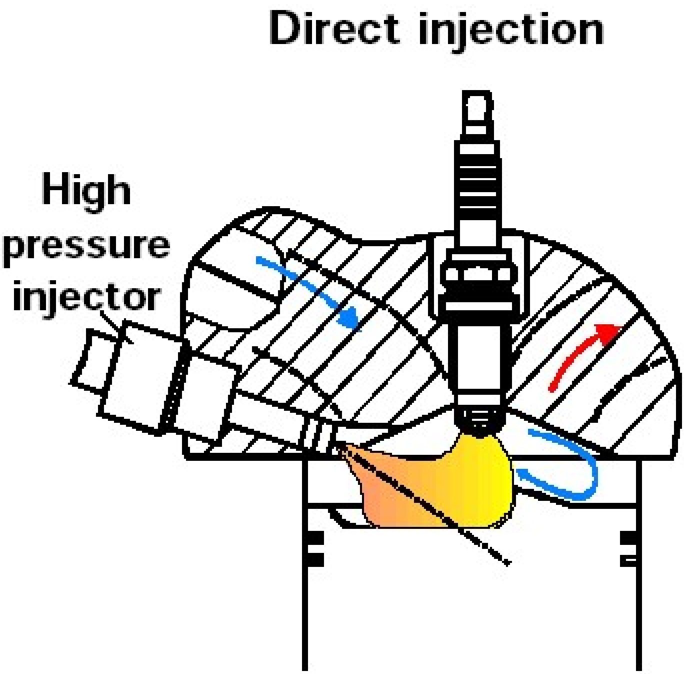
Gasoline Direct Injection Engine



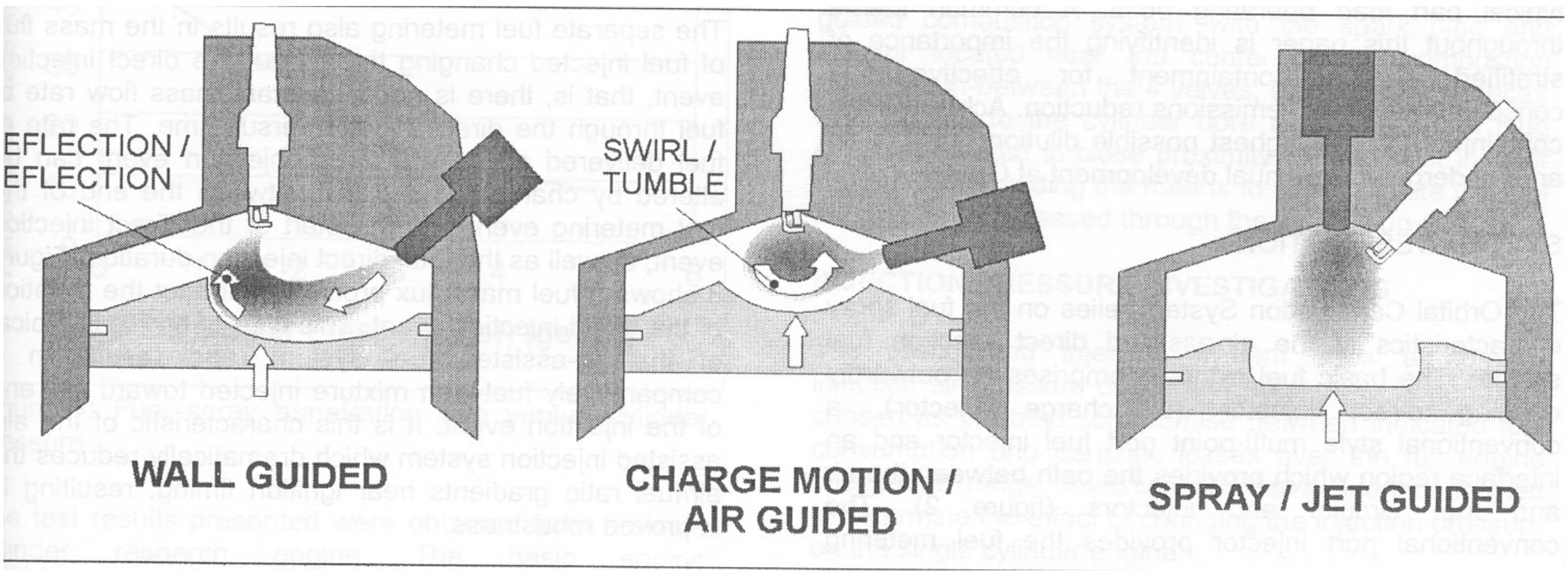
Engine Cross section

DI Combustion Chamber Design



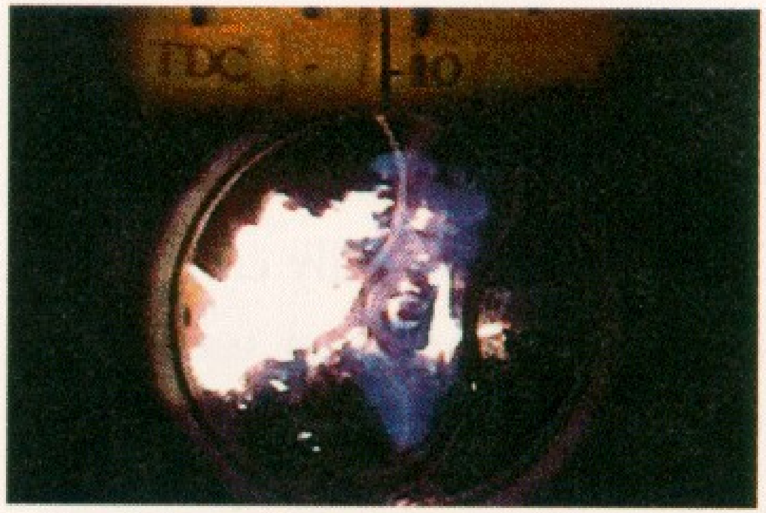


DI Stratified Charge Operation



Toyota D4 DISI Engine Combustion

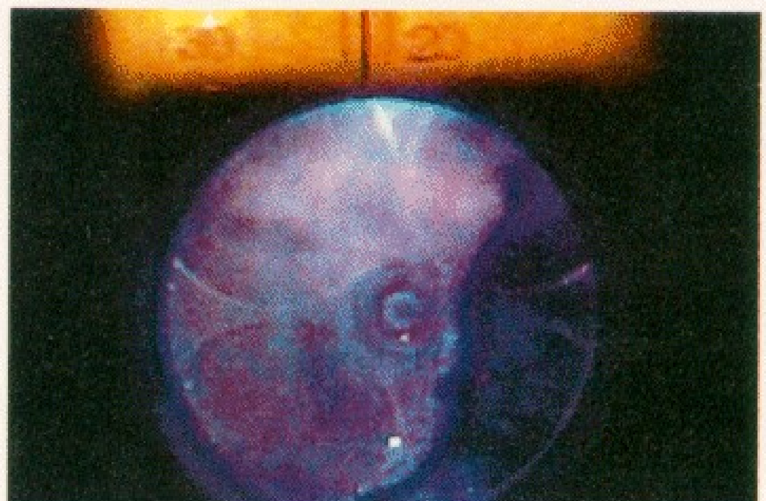
Stratified Locally
Rich Combustion
Luminous Flame



Late
Injection

**Stratified
Combustion**

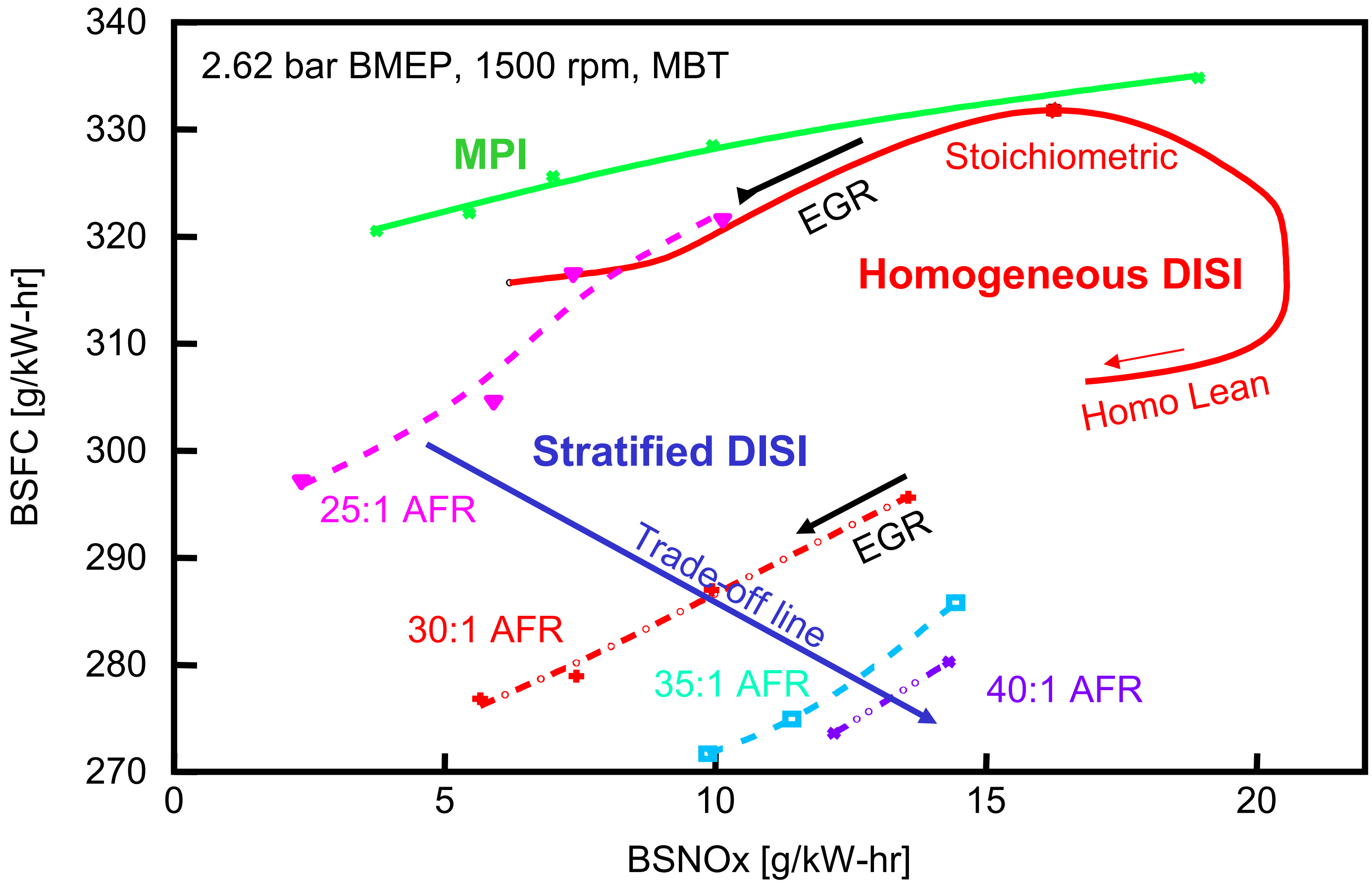
Homogeneous
Lean Combustion
Blue Flame



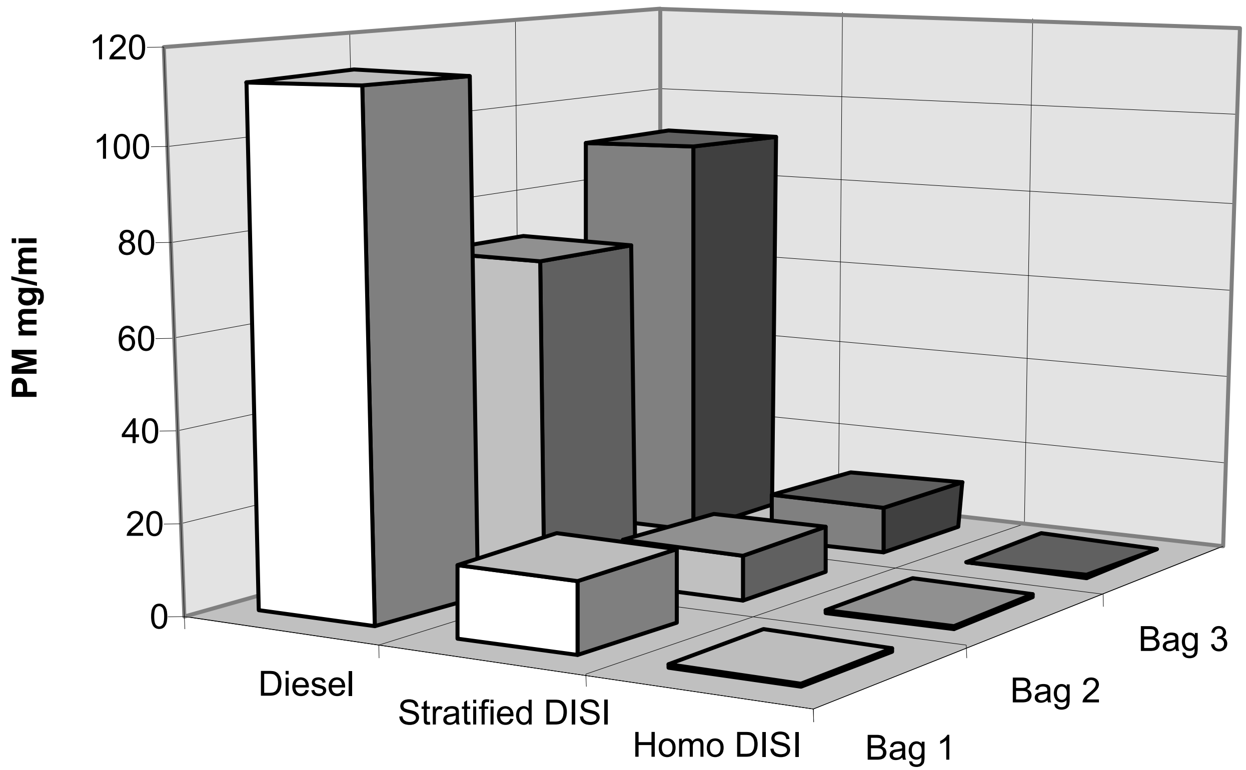
Early
Injection

**Homogeneous
Combustion**

Fuel Economy / Nitric Oxide Tradeoff



Comparison of PM (soot) emission for Diesel, Stratified DISI, Homogeneous DISI



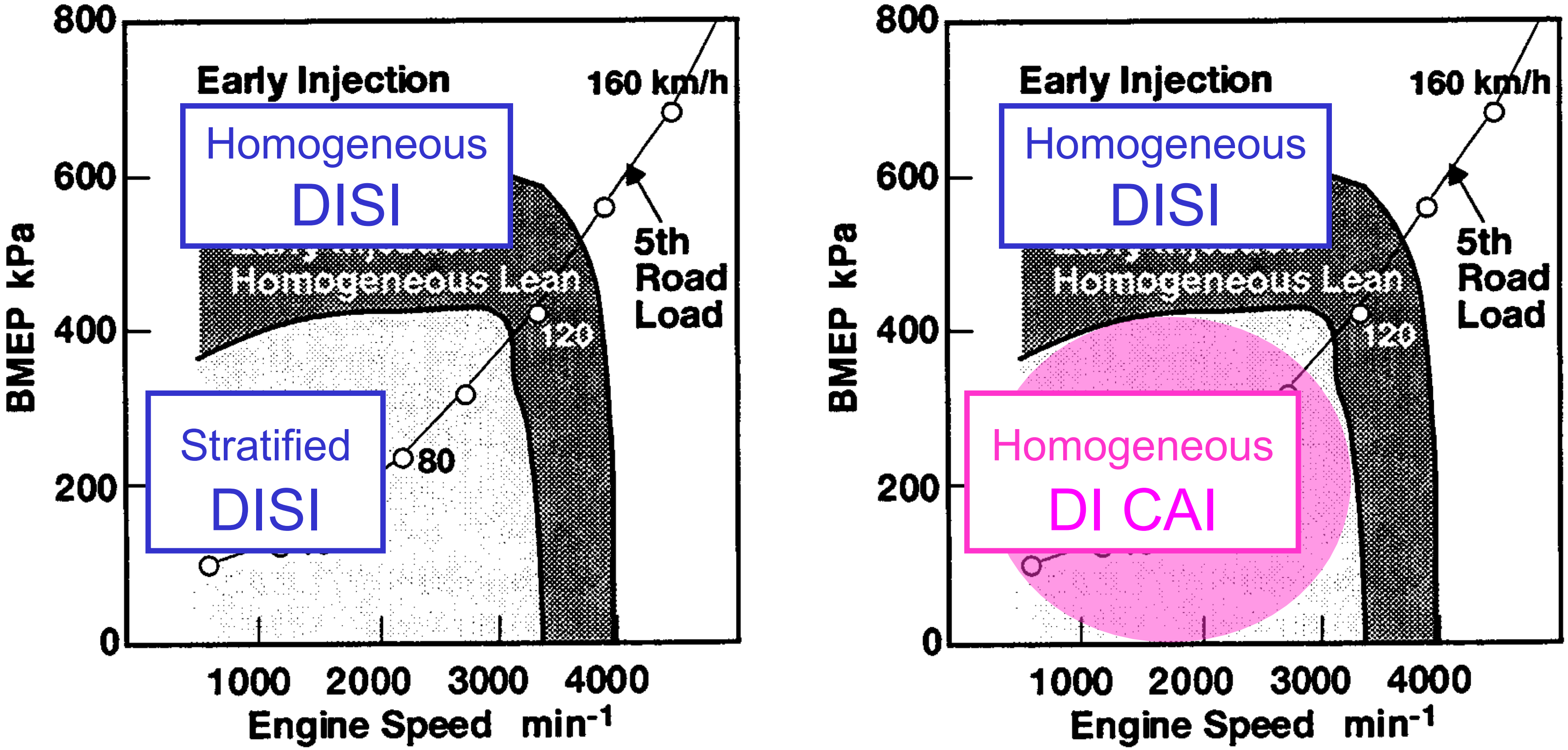
Gasoline Direct Injection Engine

With SI, Gasoline DI and stratified charge has potential of delivering 18% improvement in fuel economy against trade-off in high NOx and soot

With CAI, Gasoline DI and homogeneous charge could deliver similar fuel economy improvement with extra benefits of very stable combustion, ultra-low NOx and no soot

Therefore replace Stratified DISI with Homogeneous DI CAI during low load operation

Multi-mode Operation for DISI & CAI

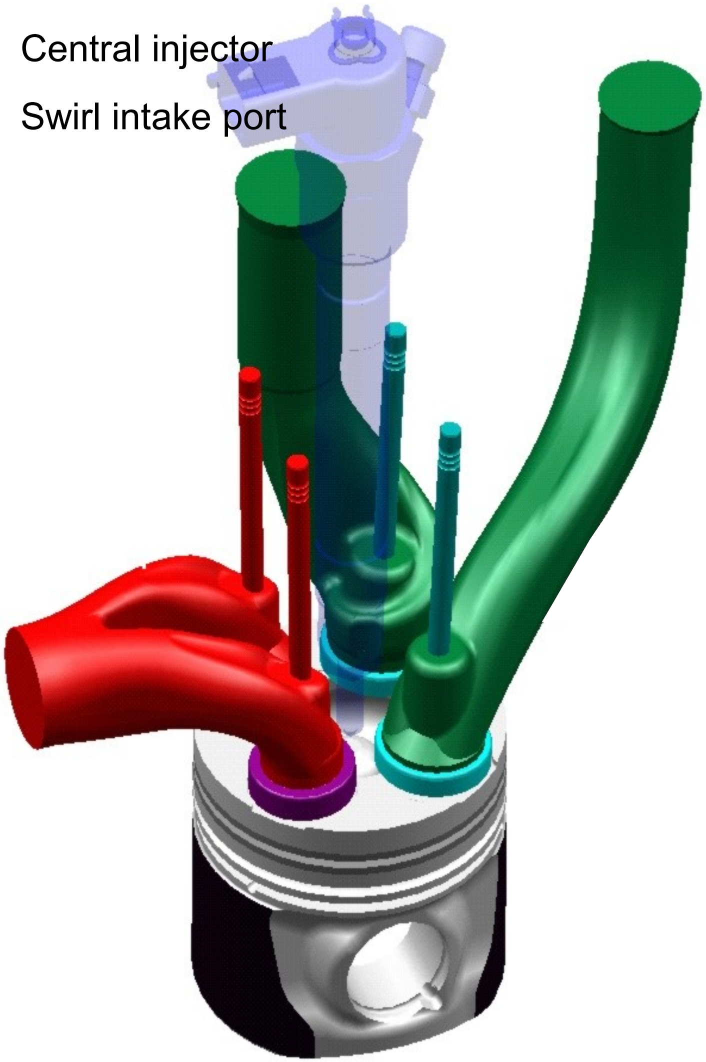


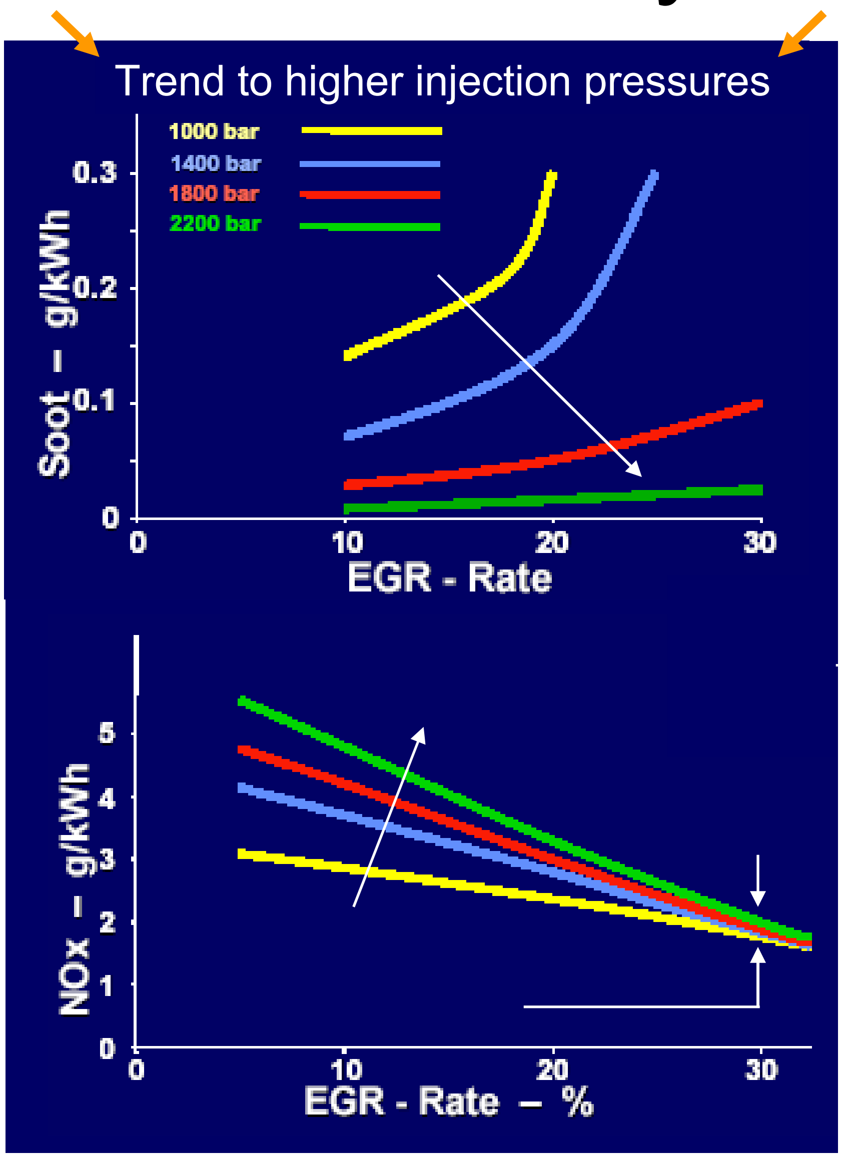
DISI with Stratified Lean Burn in low load region with trade-off of high NOx and soot

DI with homogeneous CAI in low load region with ultra-low NOx and low soot

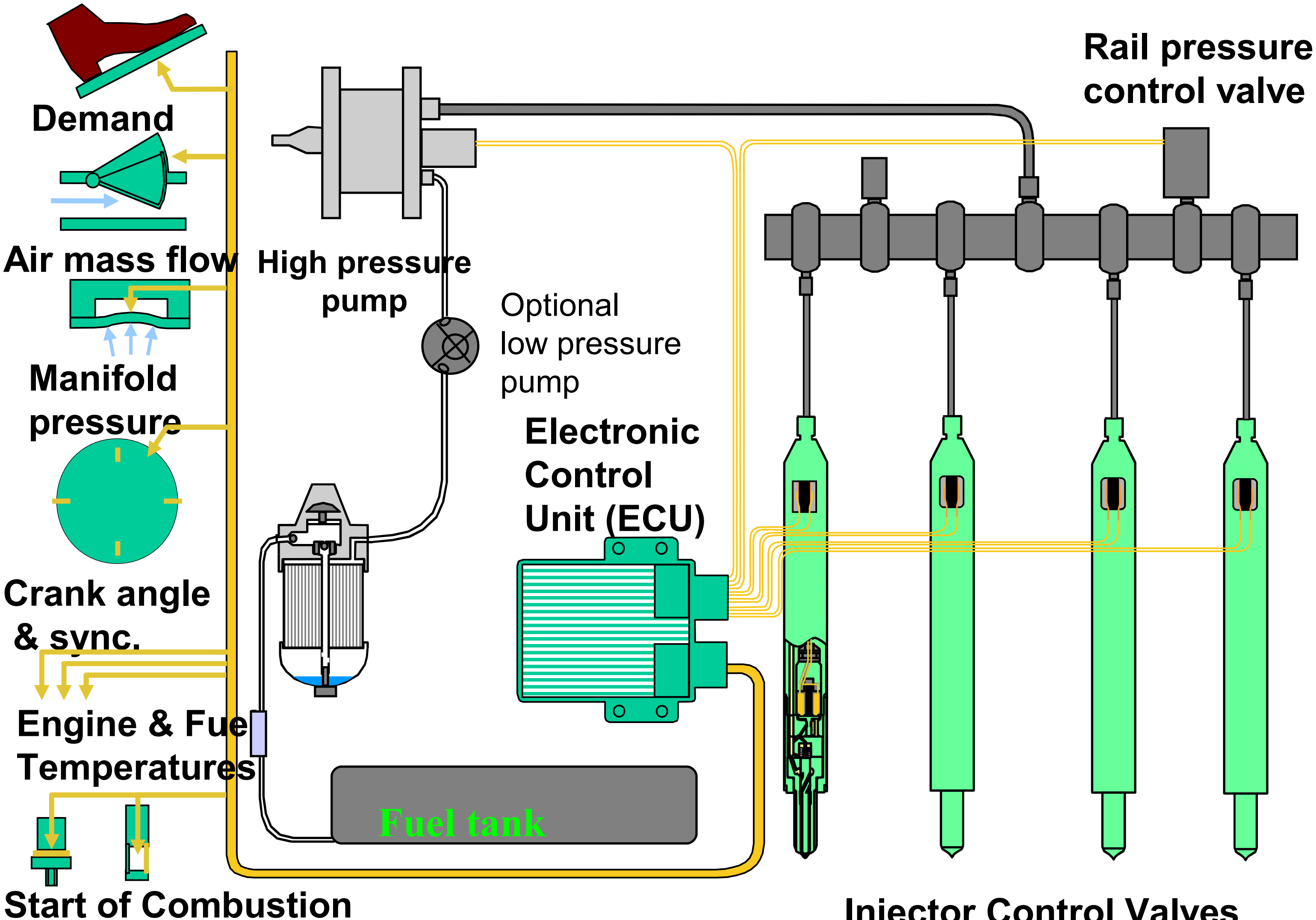
Advanced Diesel Combustion System

- 4 valves
- Central injector
- Swirl intake port

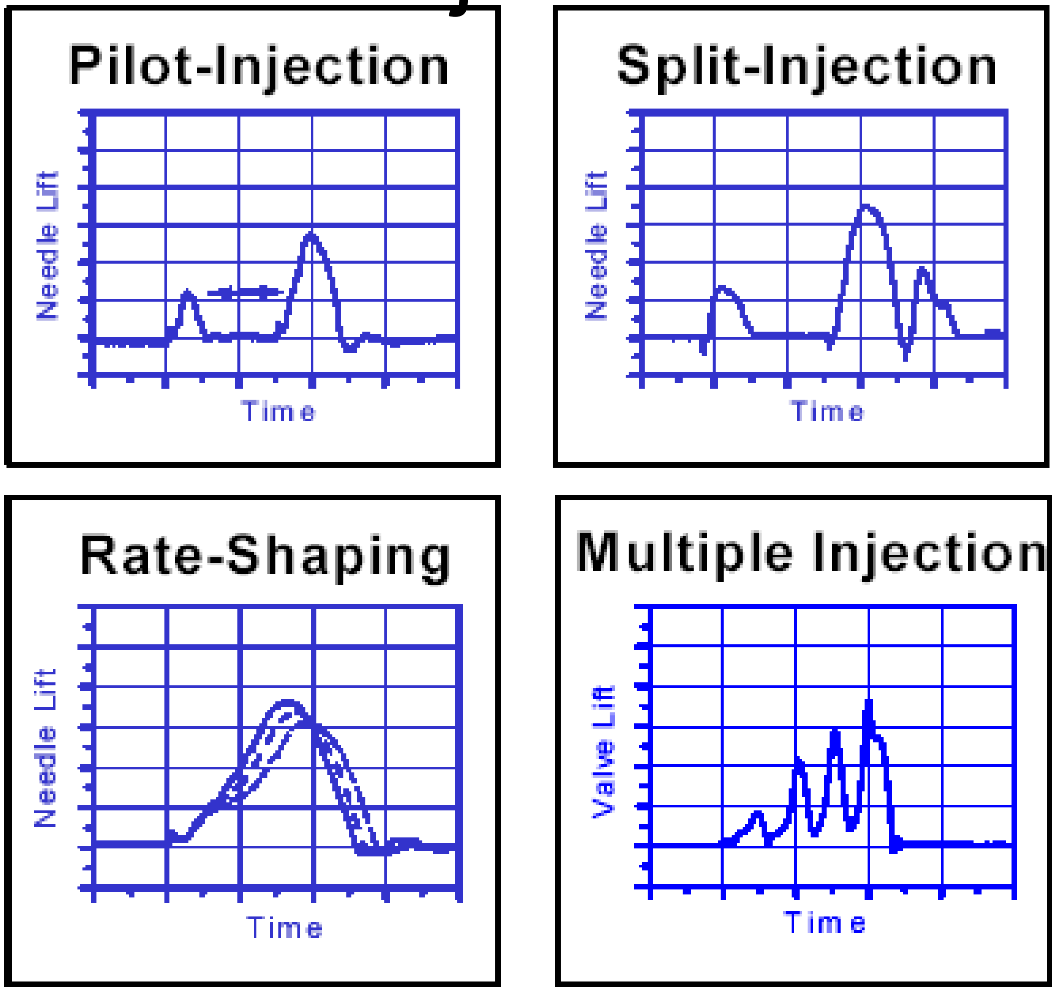


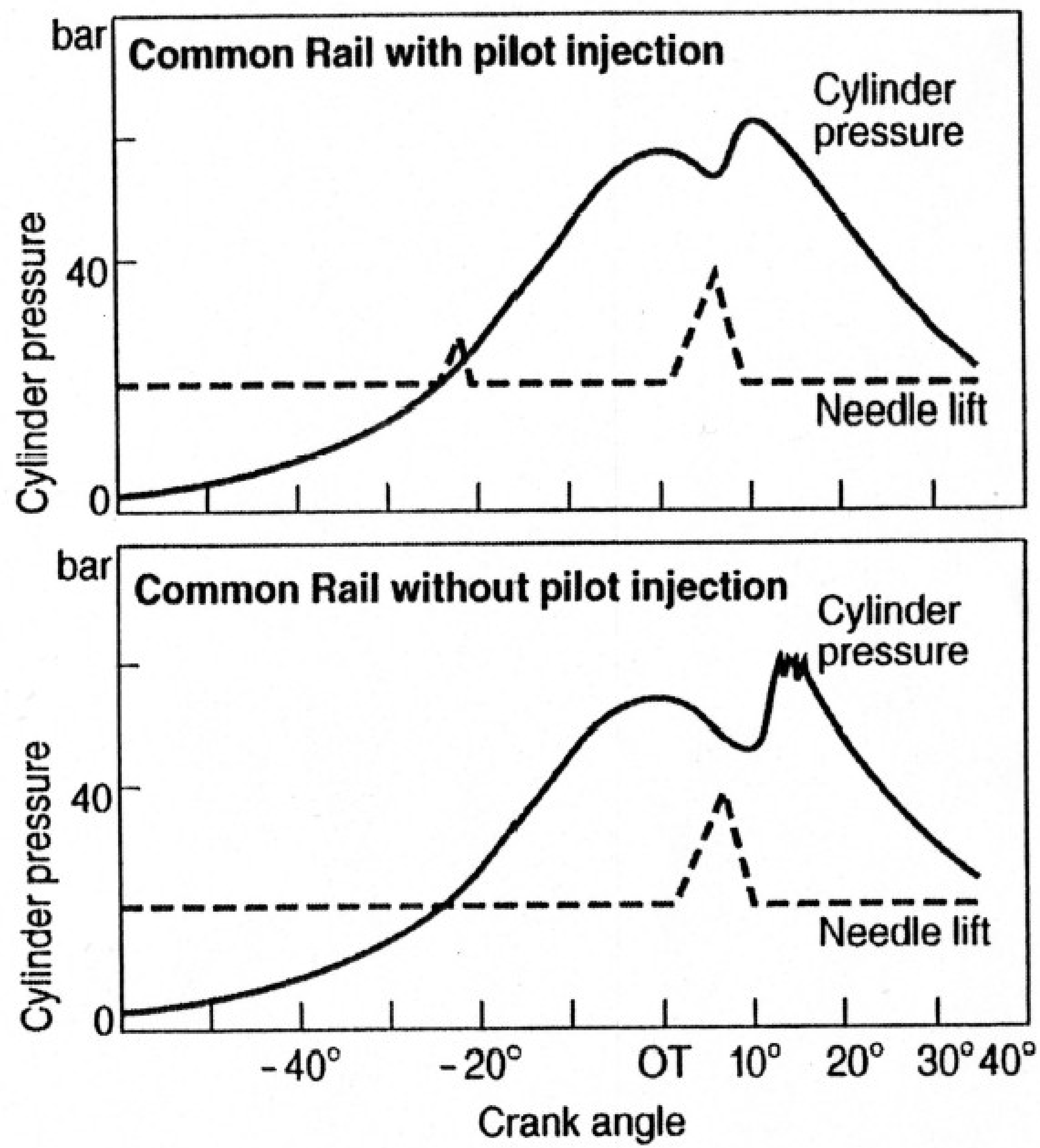


Common Rail Fuel Injection System



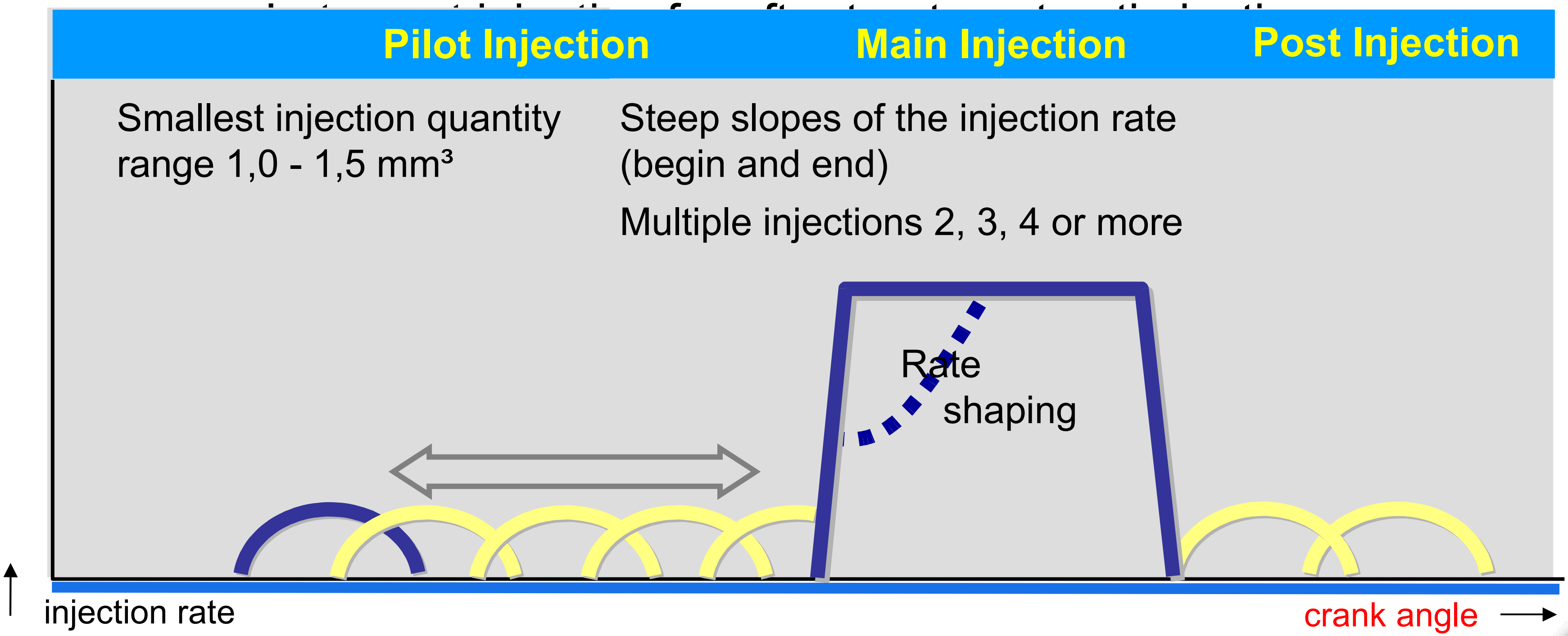
Flexible Performance Characteristic Common Rail Fuel Injection




Common Rail with pilot injection
bar
40
0
Cylinder pressure
Cylinder pressure
Needle lift
Common Rail without pilot injection
bar
40
0
Cylinder pressure
Cylinder pressure
Needle lift
-40°
-20°
OT
10°
20°
30°
40°
Crank angle

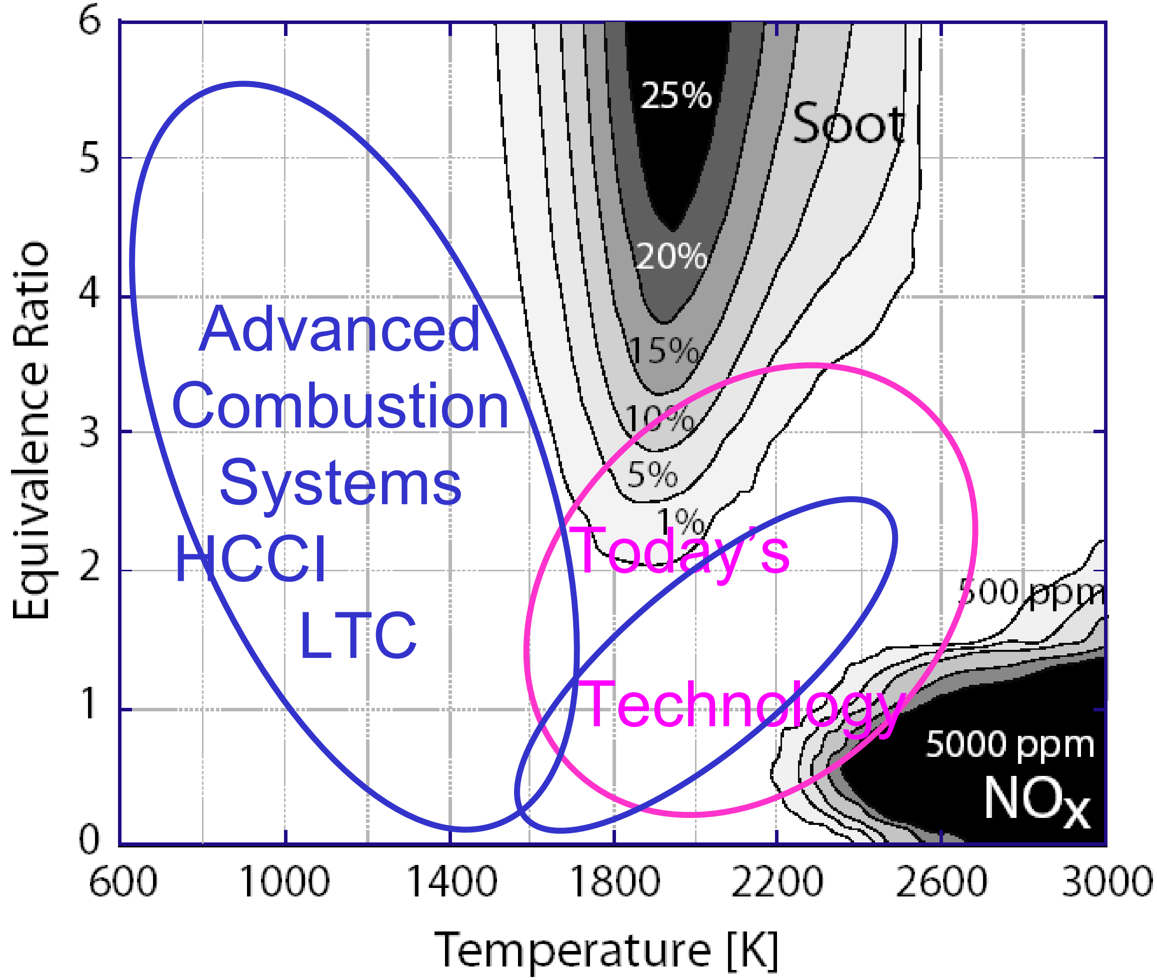
Flexible Performance Characteristic Common Rail Fuel Injection

- Multiple injection for Advanced Combustion Systems
  - Homogeneous Charge Compression Ignition HCCI
  - Low Temperature Combustion LTC
- Close pilot injection for noise and emission control
- Close post injection for emission control



Enablers for Advanced Combustion Avoiding Soot & NOx Formation

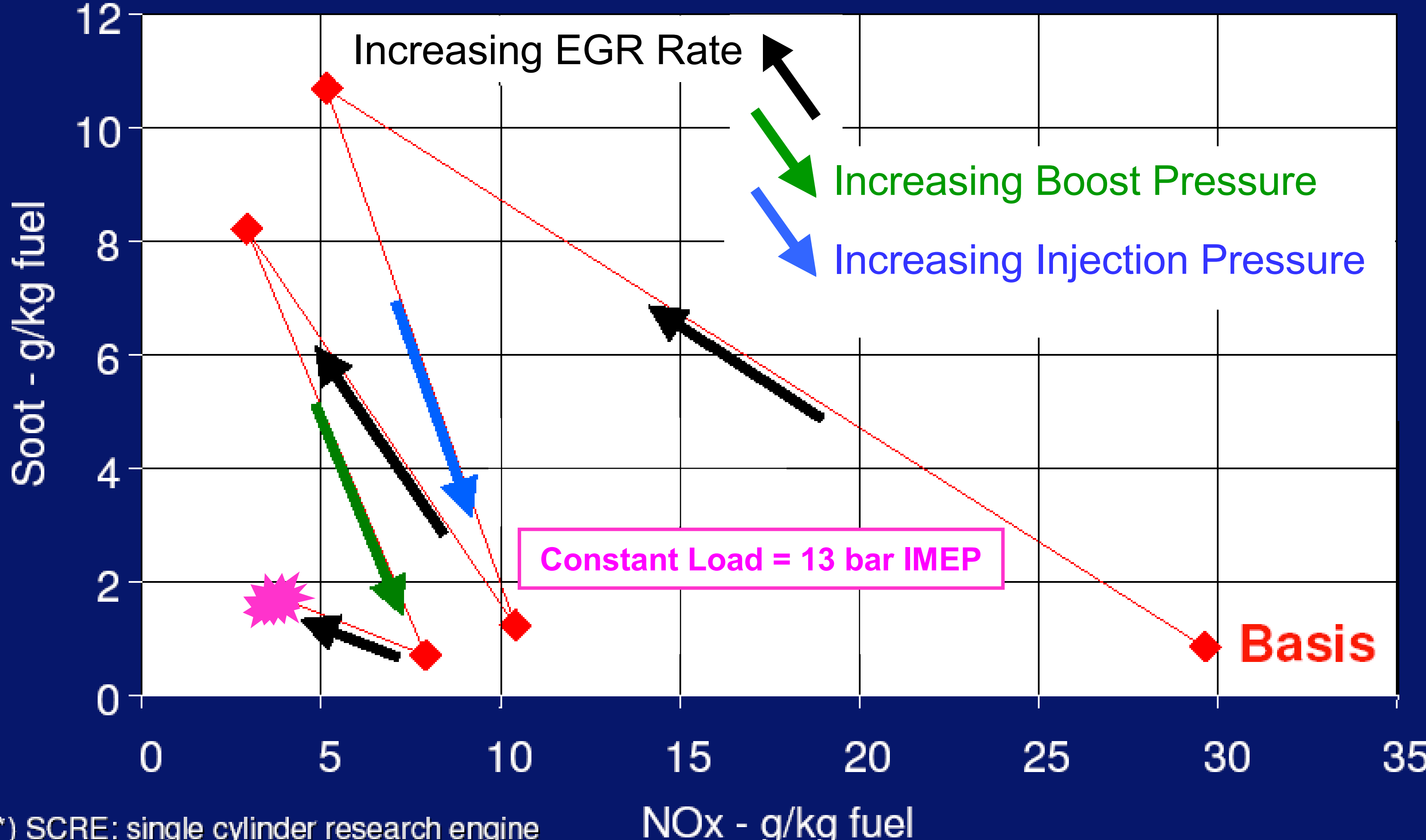
Source: Miles et al., Thiesel 2004, pp. 429-447



Synergy Steps for reducing emissions by EGR, Boost and Injection Pressure

AVL

SCRE* 0,5L/Cyl Class, 2000rpm, IMEP=13 bar, T_{intake} =const



*) SCRE: single cylinder research engine

Summary of Advanced Diesel Engine Green Technologies