February, 2008

"Far-Reaching Environmentally Friendly Motor Vehicle Technologies Eying 2020 and Beyond"

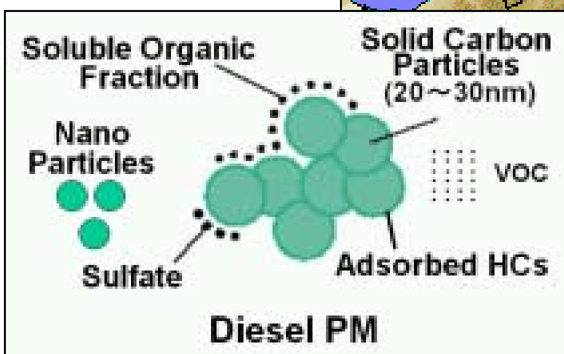
Yasuhiro Daisho
Dept. of Modern Mech. Eng.
Waseda University, Japan
Email: daisho@waseda.jp

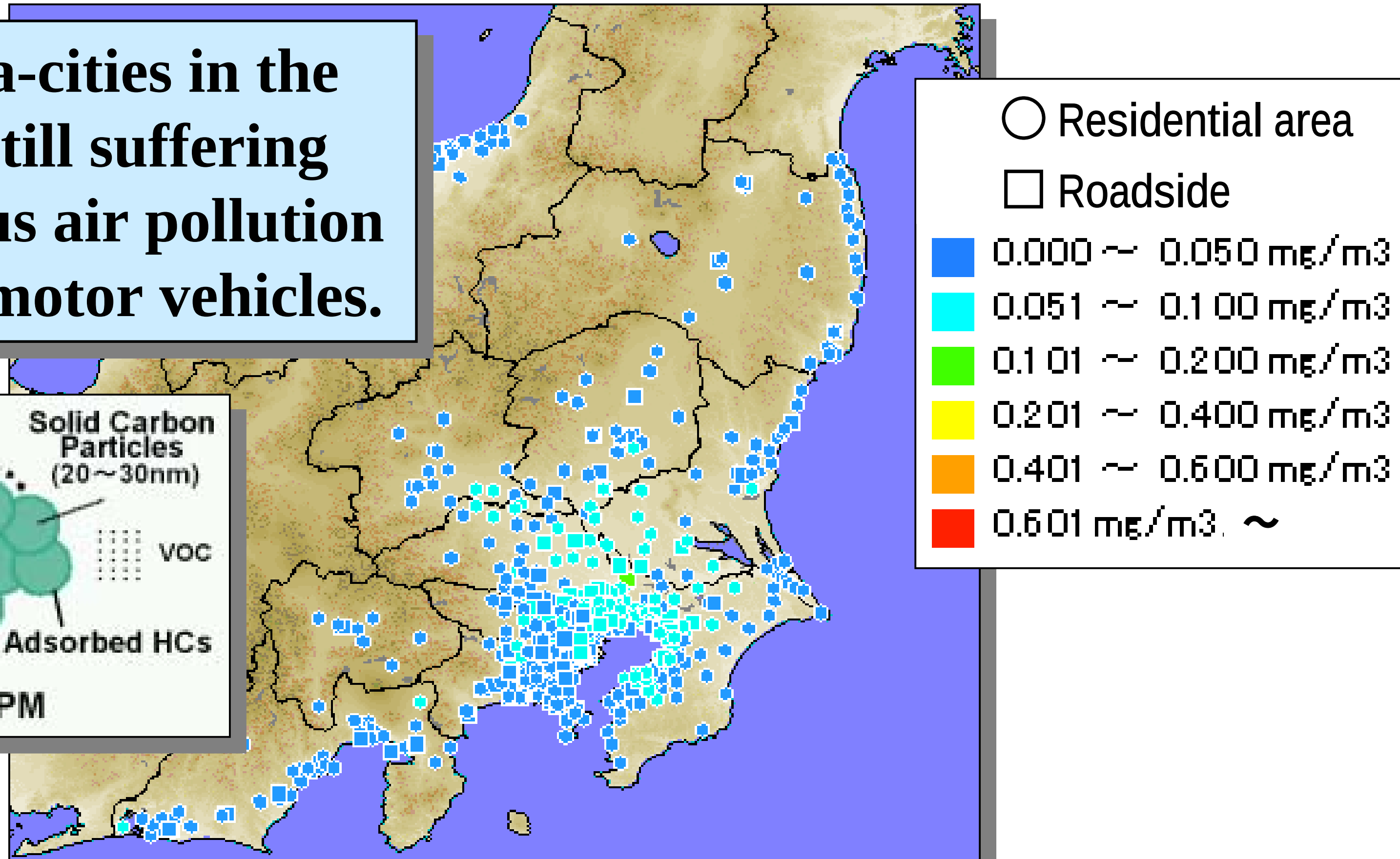
Contents

- Future Emission regulations and fuel economy standards and the related technologies
  - * Future regulations and standards
  - * Engine technologies
  - * Aftertreatment
- Possible alternative fuels and energy
- Perspectives on future vehicle and fuel technologies

Attaining NO_2 and SPM standards by 2010 is one of the most important issues for the Japanese government.

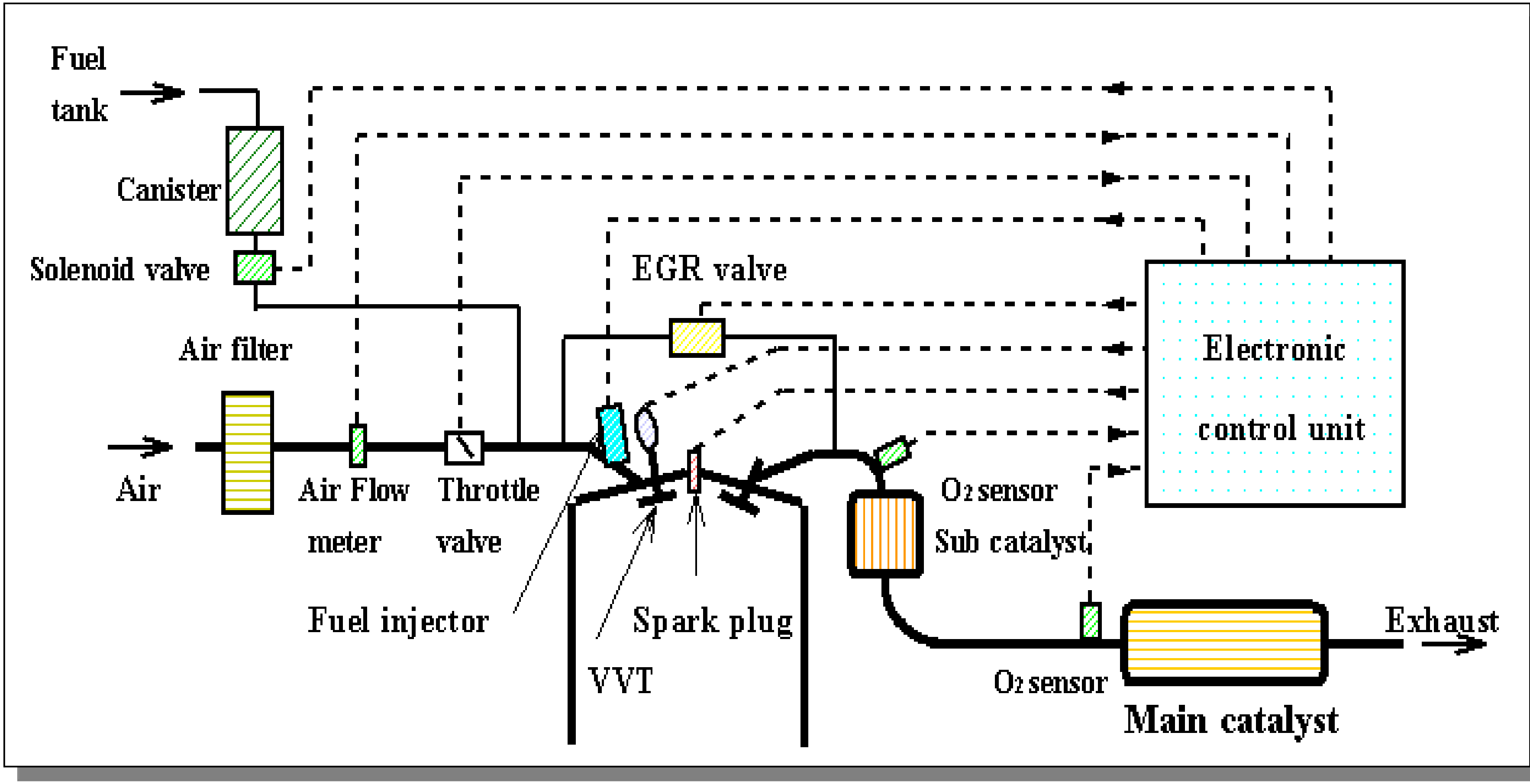
Many mega-cities in the world are still suffering from serious air pollution caused by motor vehicles.



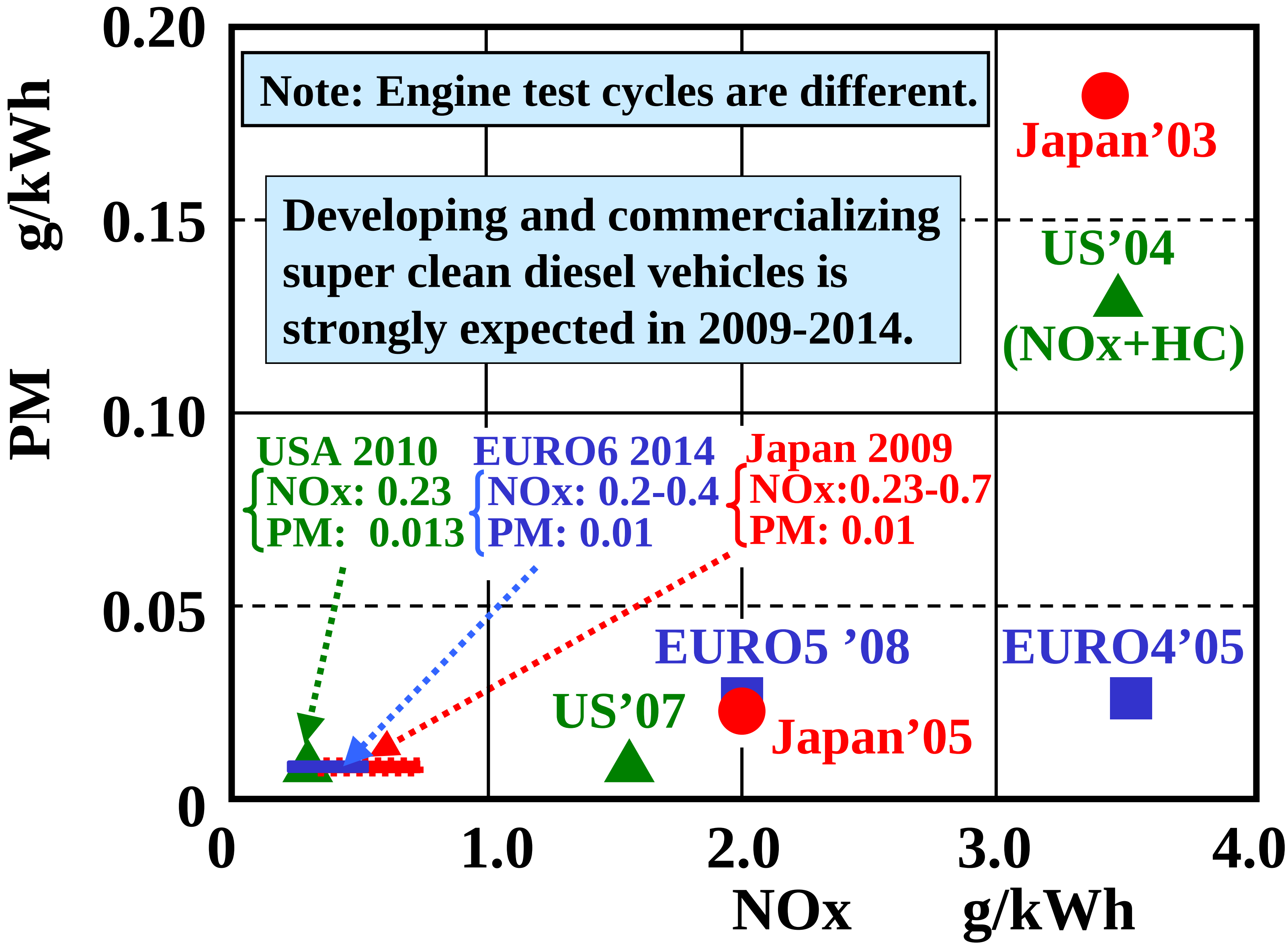


An SPM Concentration Map in Kanto District
7:00 pm, December 5, 2006
(Website of Ministry of the Environment)

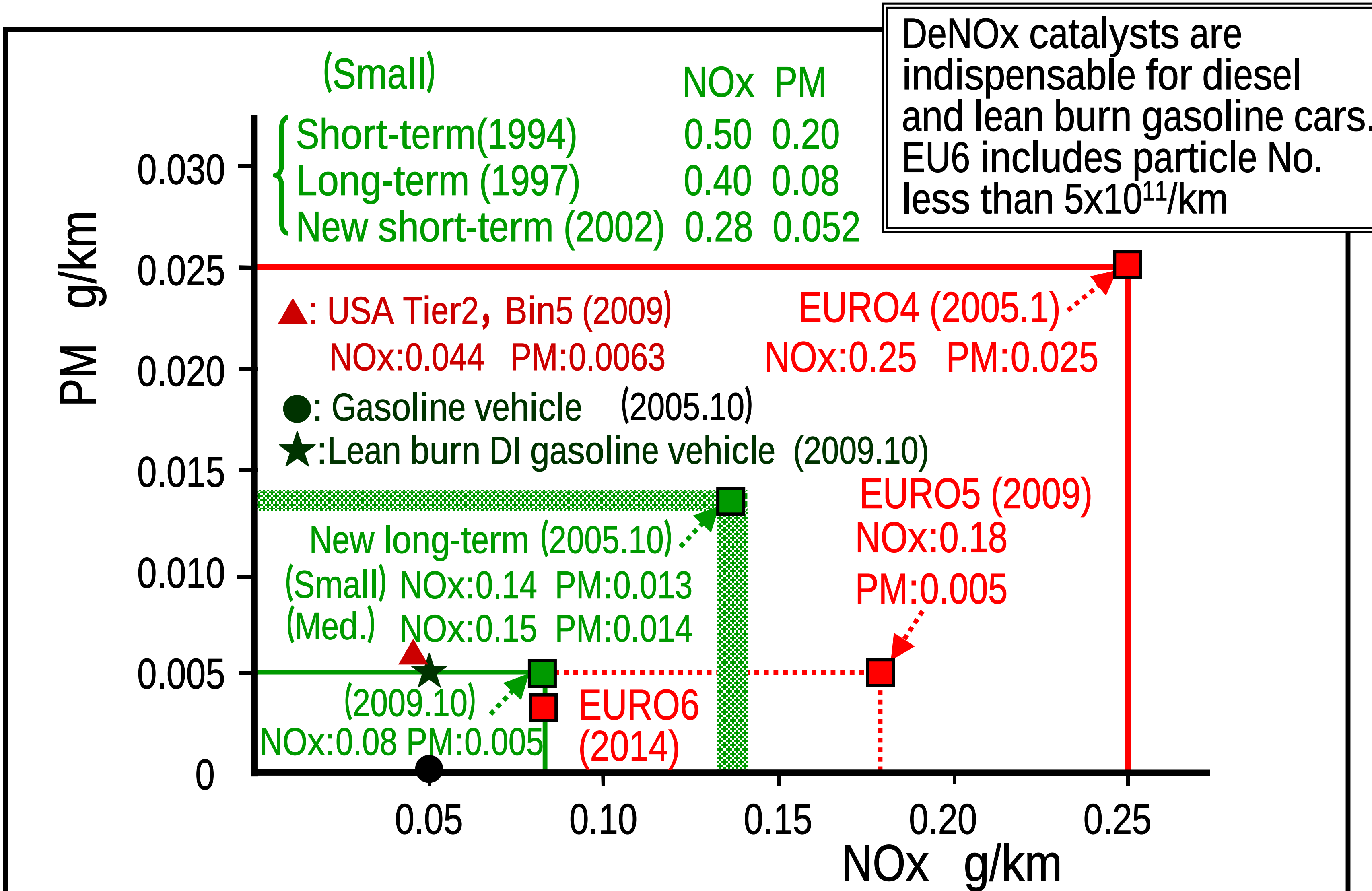
Gasoline vehicles are achieving almost zero emission levels by significantly reducing cold start and warm-up emissions.



A Typical System for Reducing Emissions in the Gasoline Engine

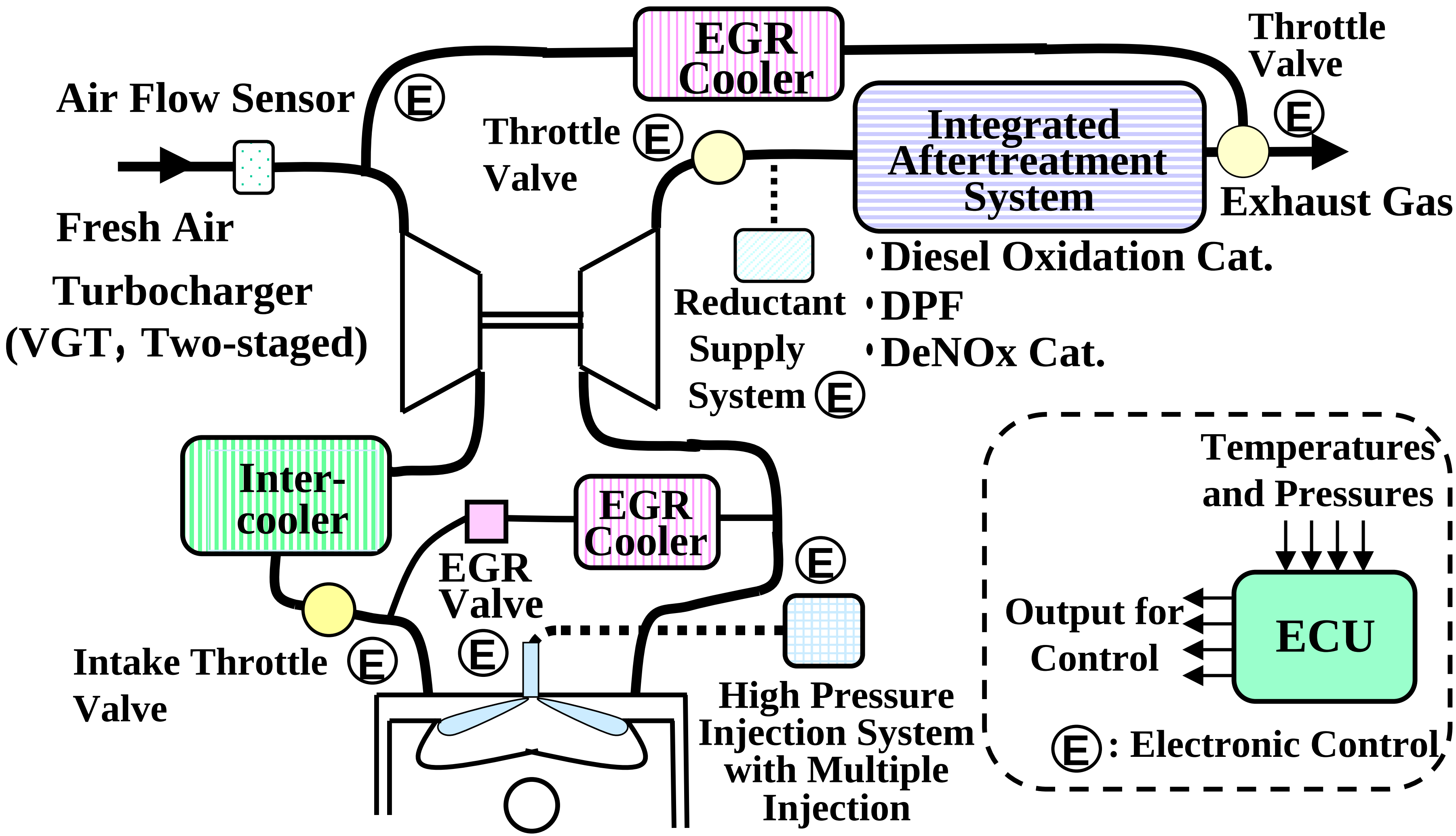


HD Diesel NOx and PM Emissions Regulations

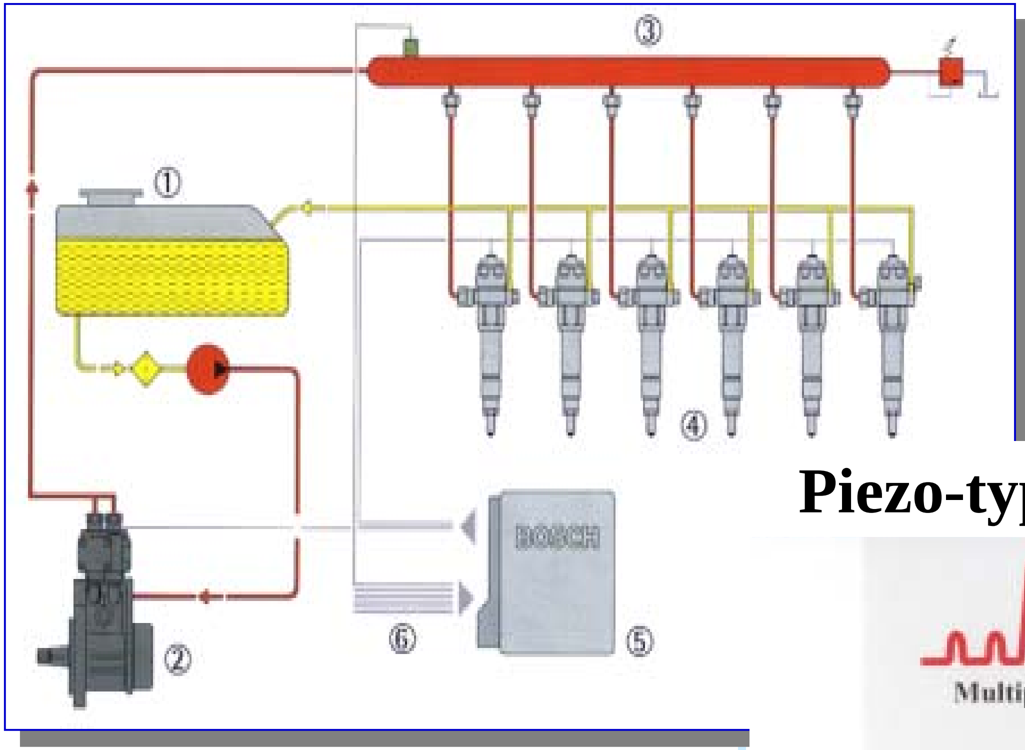


NOx and PM Emissions Regulations for Diesel Passenger Cars in Japan, the EU and the USA

Ensuring efficiency, durability and cost reduction are essential to comply with more stringent diesel emission regulations to be in effect in Japan, the EU and the U.S.A. around 2010 and later.

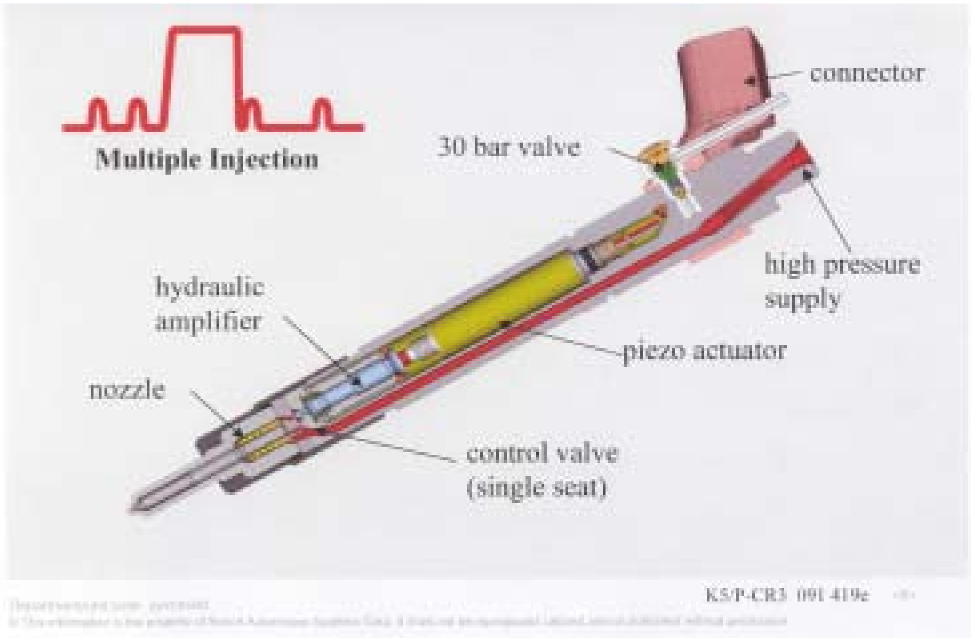


Typical Advanced Diesel Emission Control System



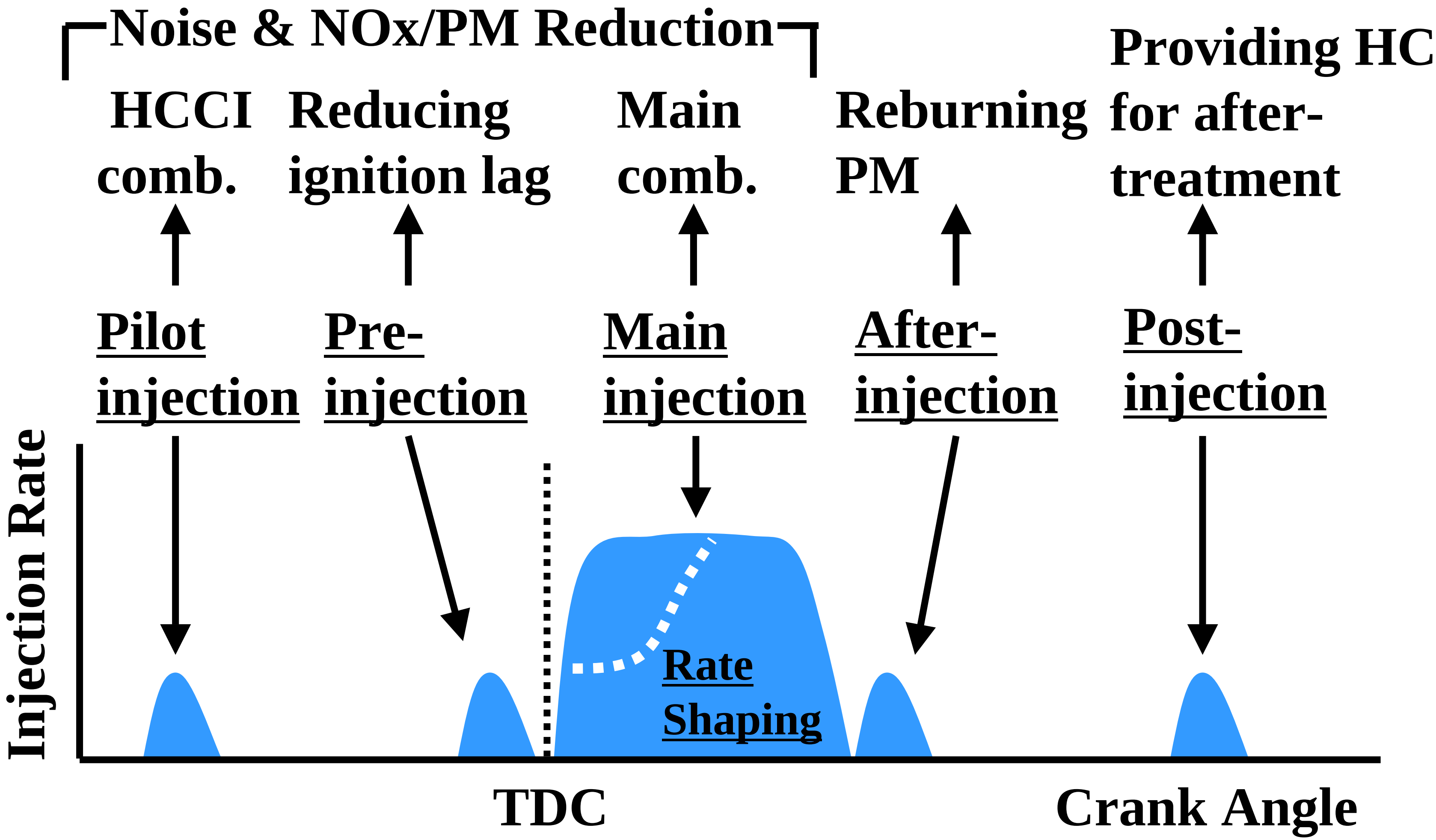
Common Rail System
(Injection Pressure:
200 to 220 MPa)

Piezo-type Injector for Passenger Cars

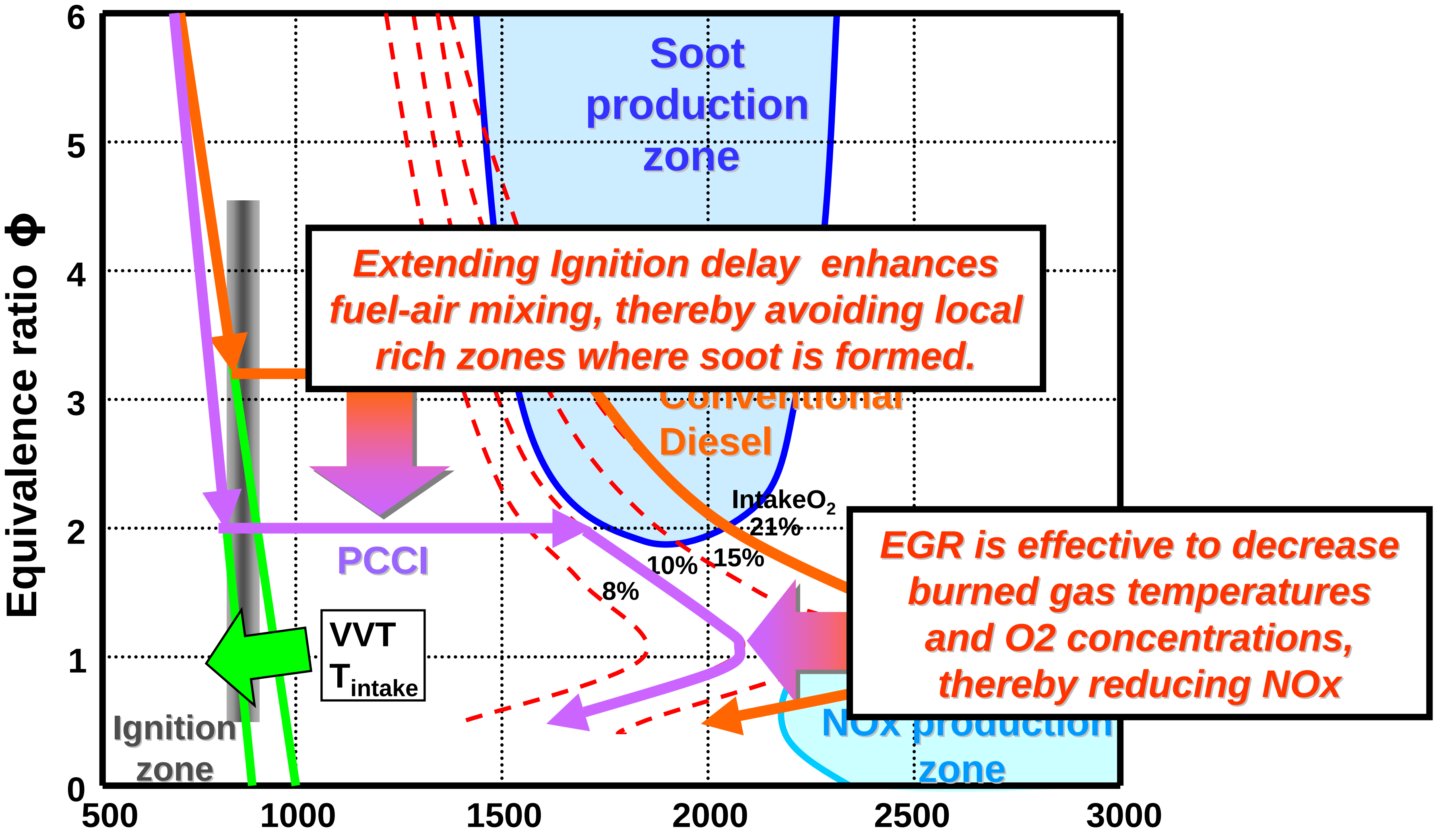


(Source: Bosch)

High-Pressure Injection Systems



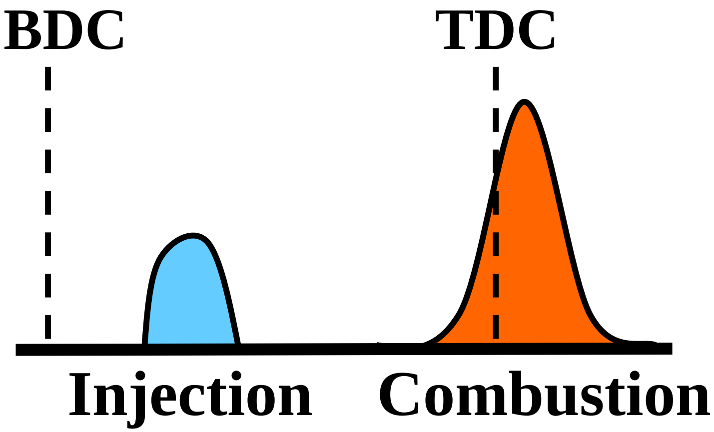
Controlling Diesel Combustion by means of Multiple-Injection



(M. Potter, DEER 2006)

Soot and NOx Formation Zones on Φ-T Map

HCCI (Homogeneous or Premixed Charge Compression Ignition) Combustion



●Significantly low NOx and PM emissions at lower load, achieving a high efficiency comparable to that of diesel

▲High HC and CO emissions (An oxidation catalyst is needed.)

▲Unacceptably explosive combustion at heavy load

■Highly dependant on temperatures and charge heterogeneity

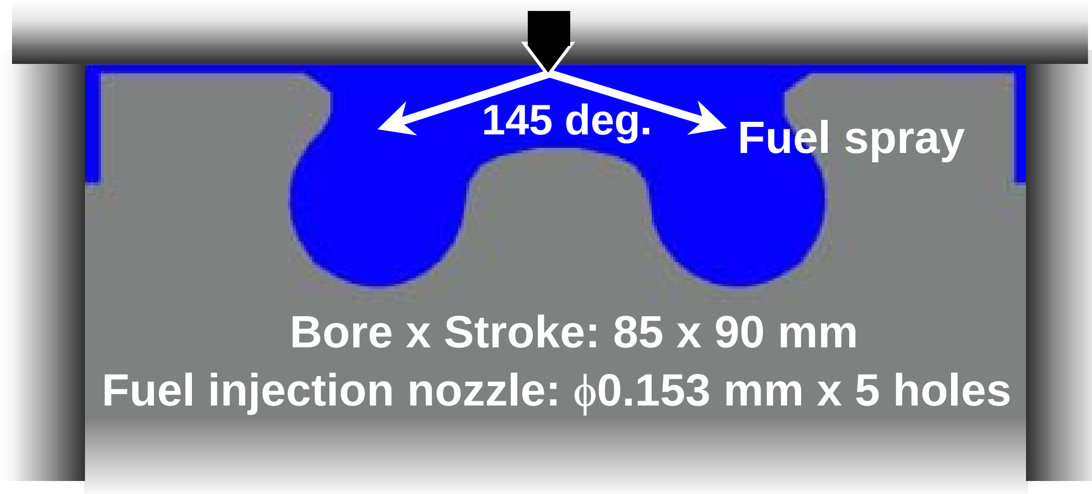
■Precise combustion control systems must be developed, including multiple injection, EGR, variable valves, ignition sensing devices, etc.

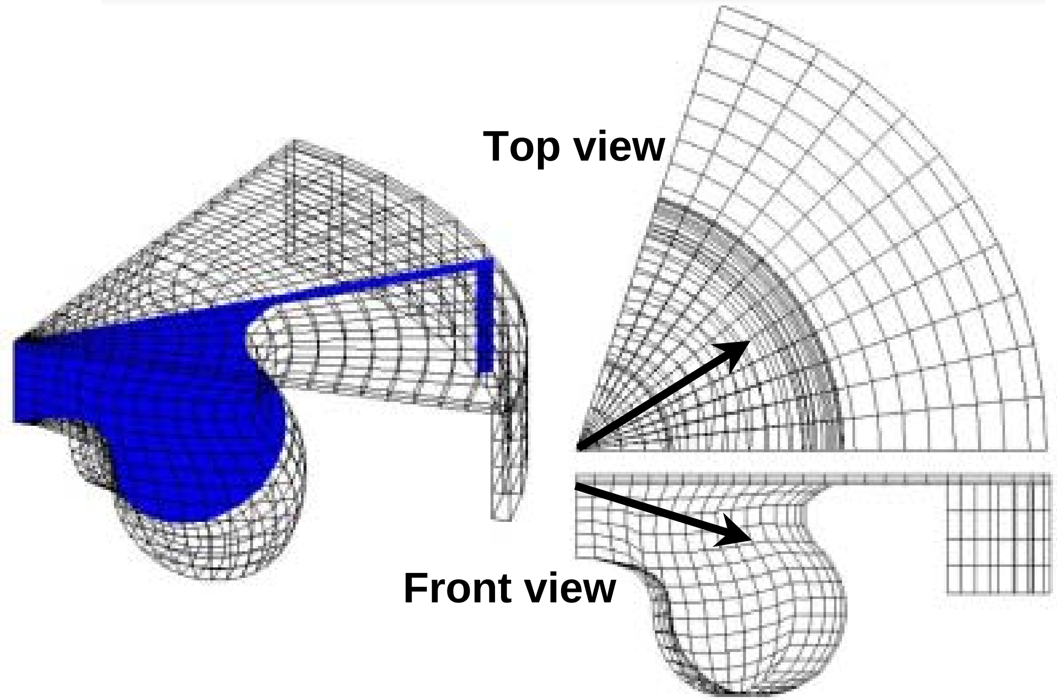
■The concept may be applicable to improve SI engine's efficiency and emissions at low load, possibly with direct-injection stratified charge.

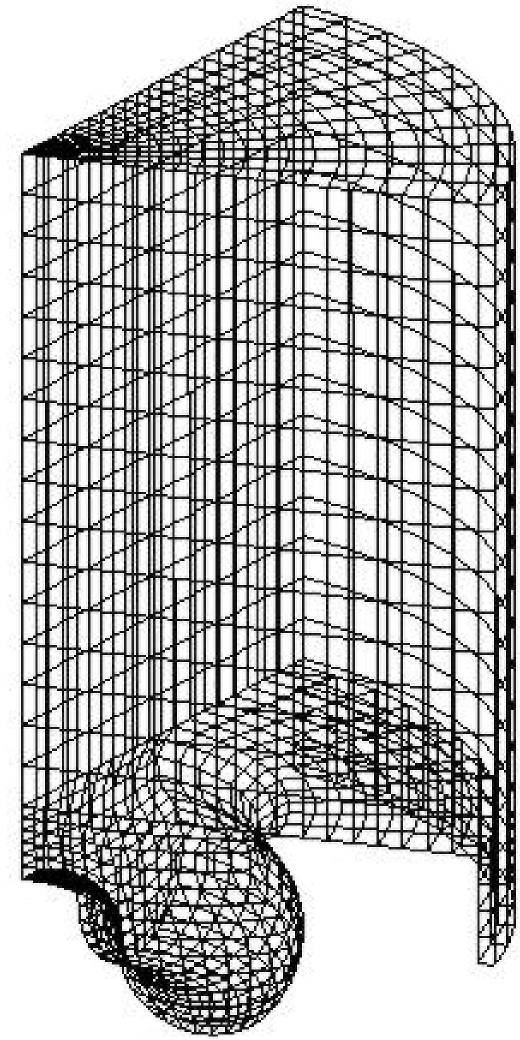
■Numerical combustion modeling is significantly required.

Methods for PCCI Combustion

Method	●: Advantage ▲: Disadvantage
Early injection	▲Fuel deposition on the cylinder wall ▲Lower controllability (longer ignition delay) ▲Explosive combustion at heavy load
Late injection (MK concept)	●Lower peak pressure and pressure rise ▲Deceased efficiency (High swirl mixing)
Low compress. ratio	●Increased mixing time ▲Decreased efficiency
Variable valve mechanisms	●Higher controllability ▲Complex mechanism ●Ensuring efficiency (Miller cycle)







(Waseda Univ.)

A CFD Model Combined with Detailed Chemistry

EGR0% (Inj.timing : -3.5deg.ATDC)

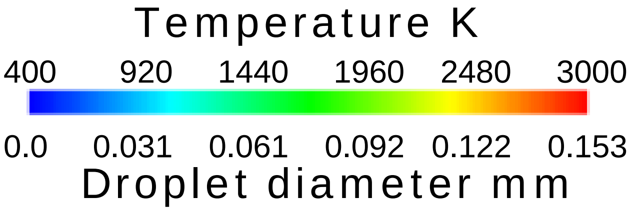
EGR40% (Inj.timing : -7deg.ATDC)

EGR40%+LIVC (Inj.timing : -14deg.ATDC)

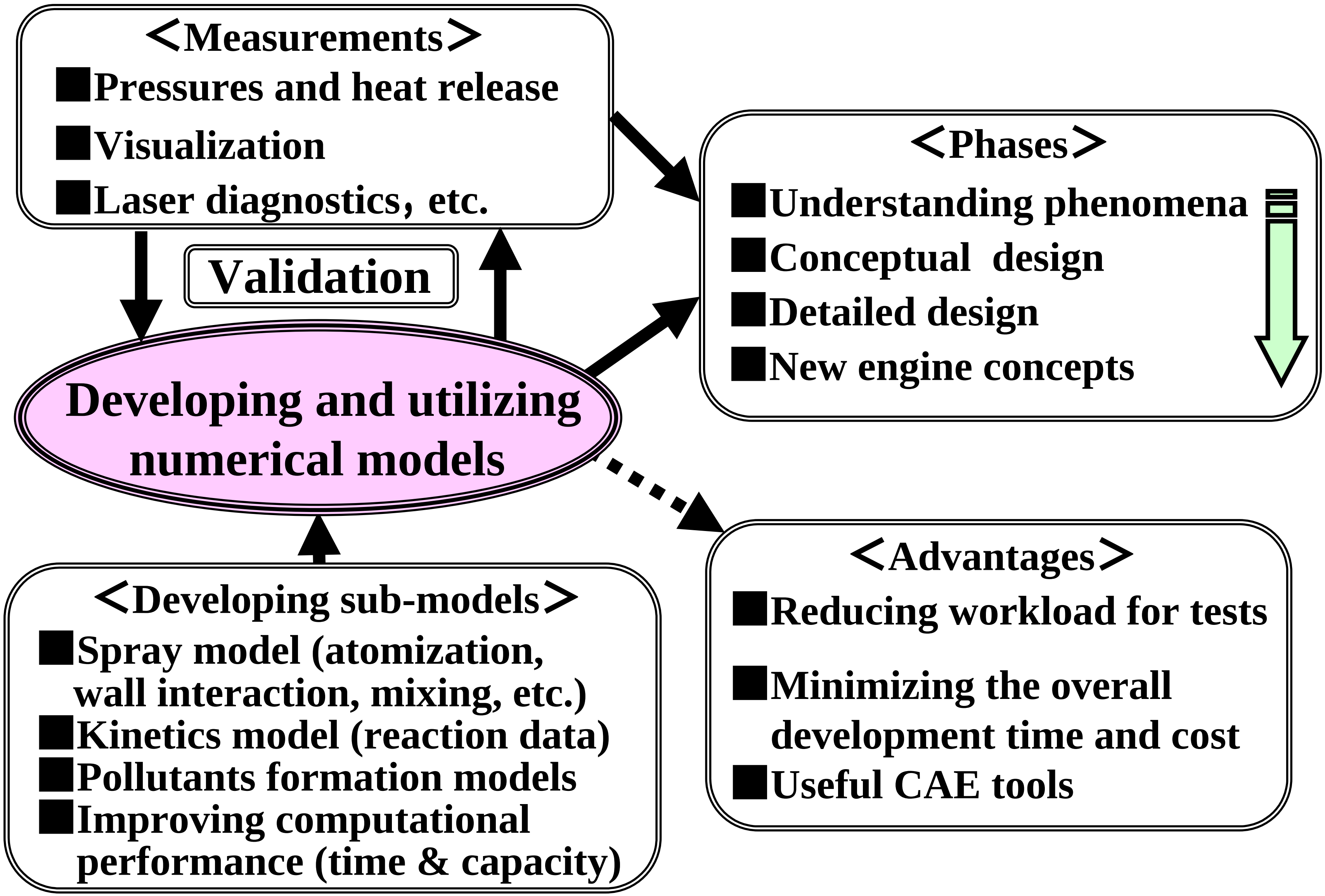
Ne: 1,800 rpm
Load: 33%
Boost: 50 kPa

-30deg.ATDC

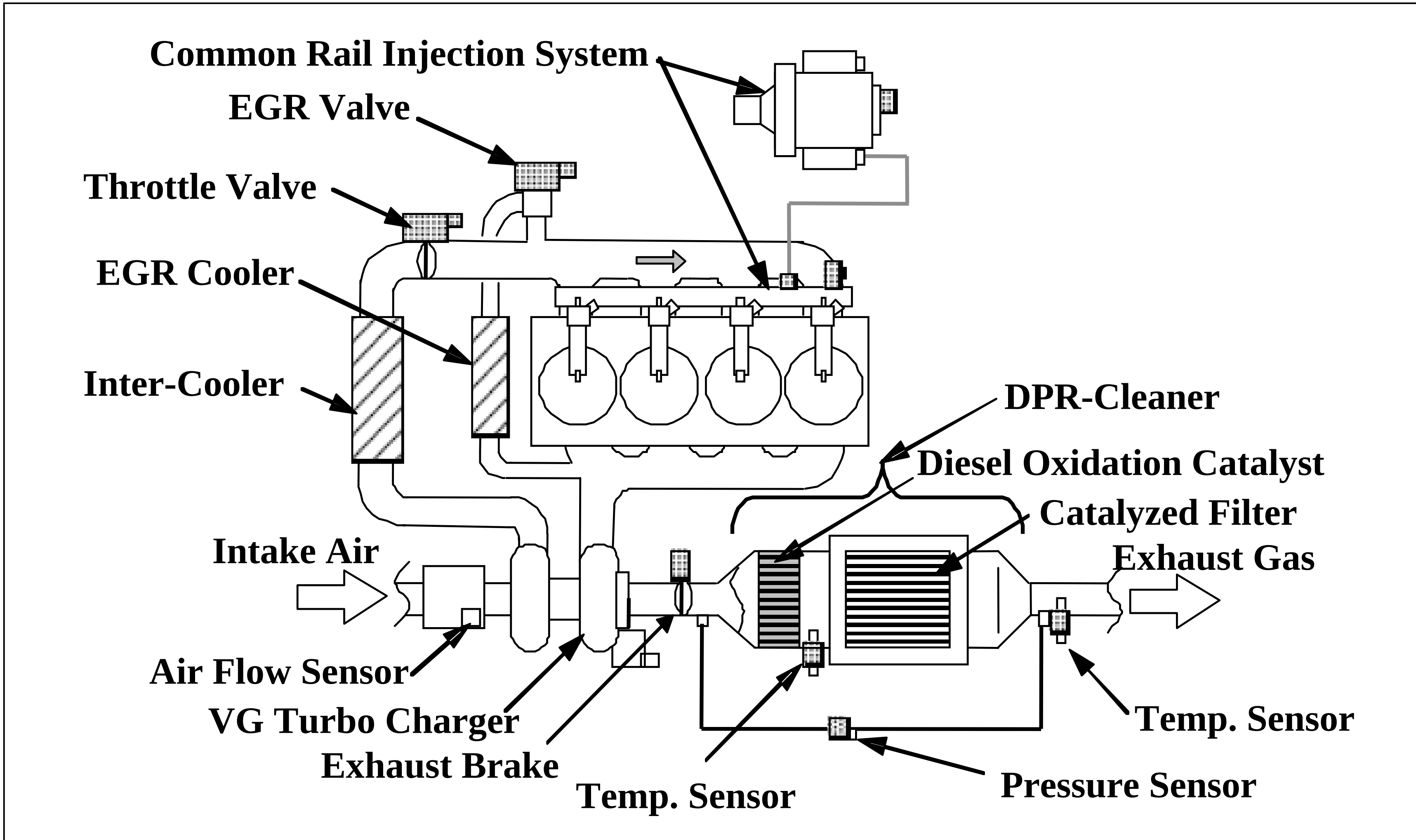
PCCI Combustion



Calculation results
Gas Temperatures and Fuel Droplet Dynamics
(Y. Murata, Y. Daisho, Waseda Univ.)

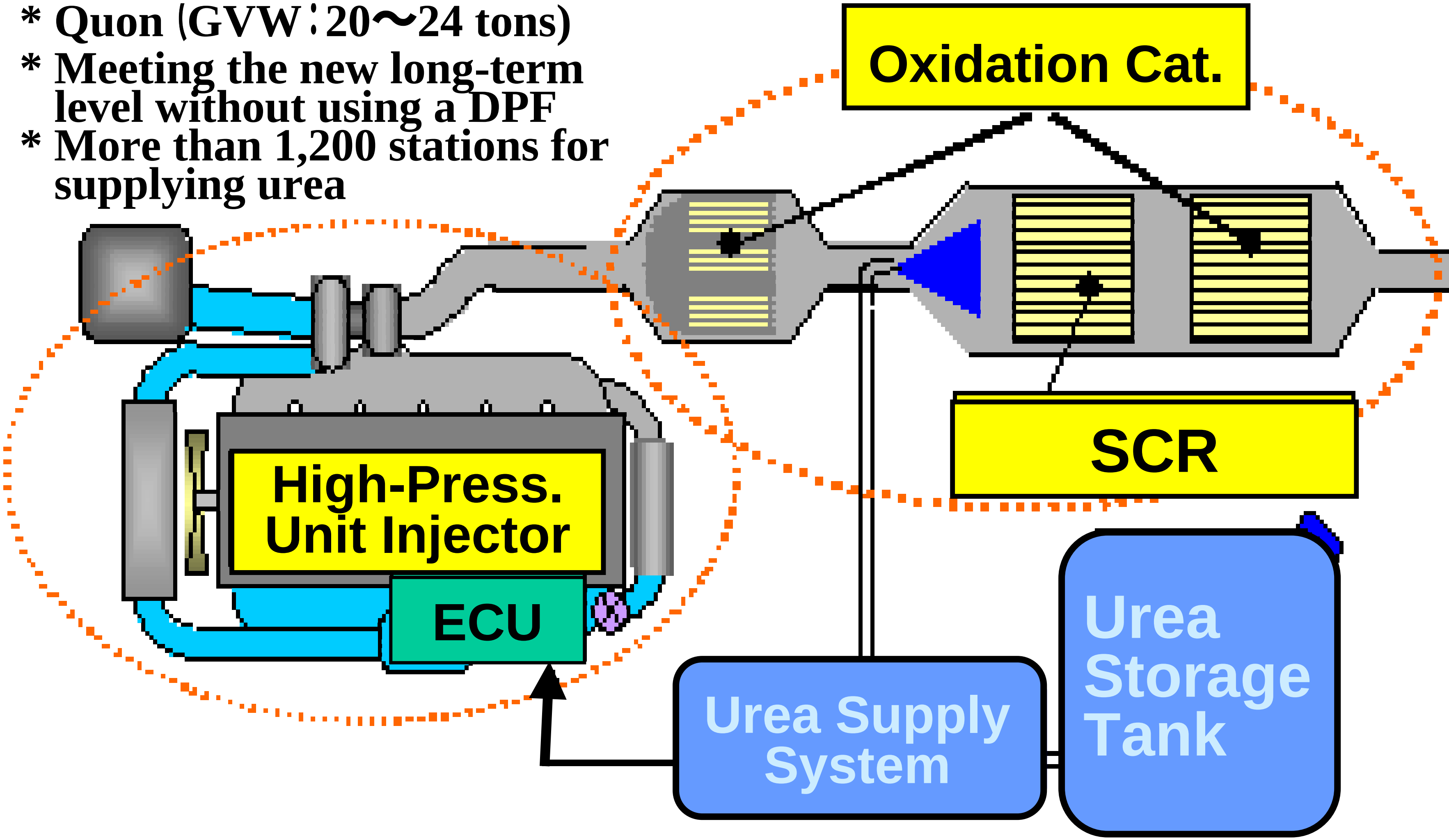


Roles of Numerical Modeling for Engine R&D, Design and Production

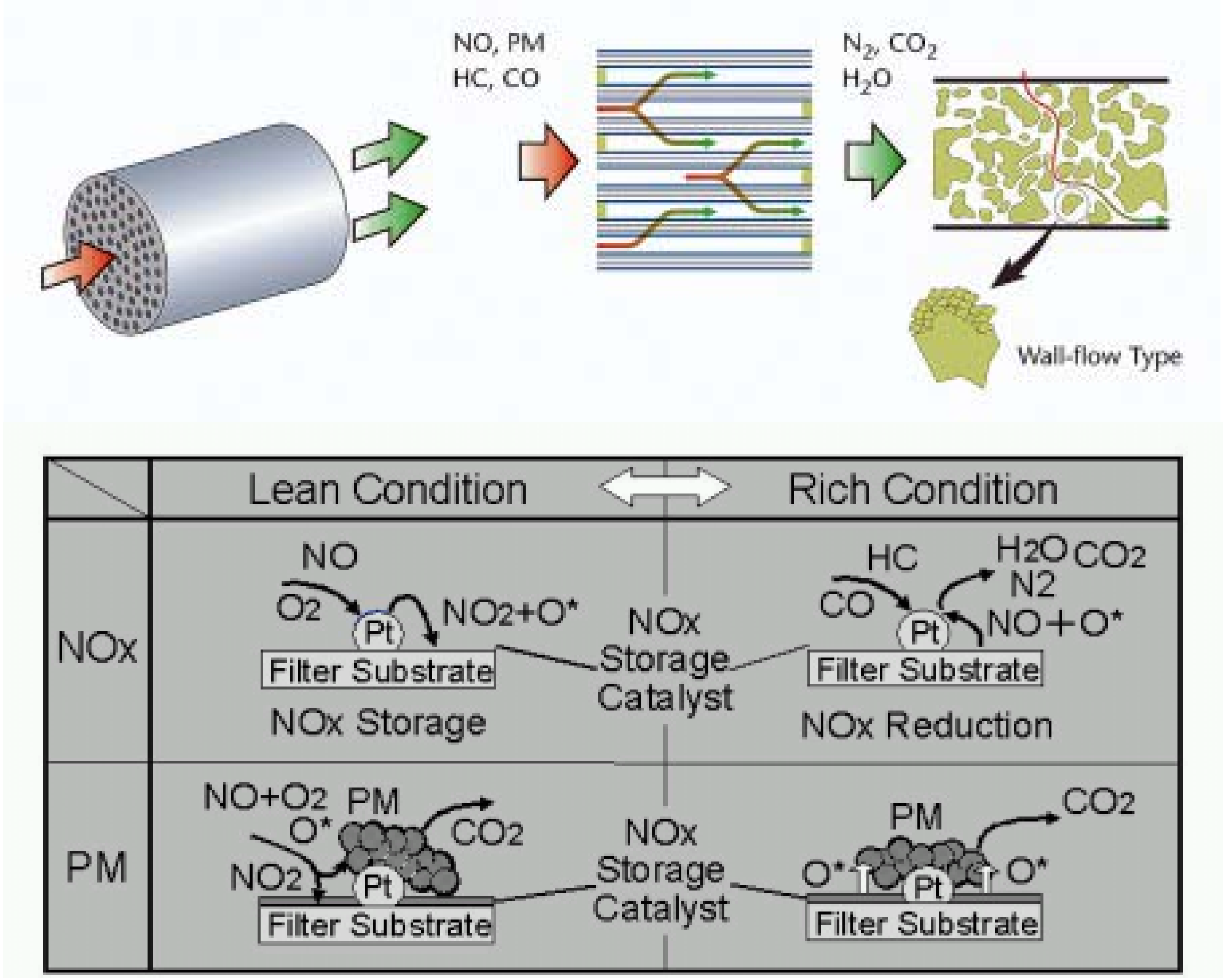


A Precisely Controlled DPF System “DPR” (Hino Motors, 2003)

* Quon (GVW：20～24 tons)
* Meeting the new long-term level without using a DPF
* More than 1,200 stations for supplying urea

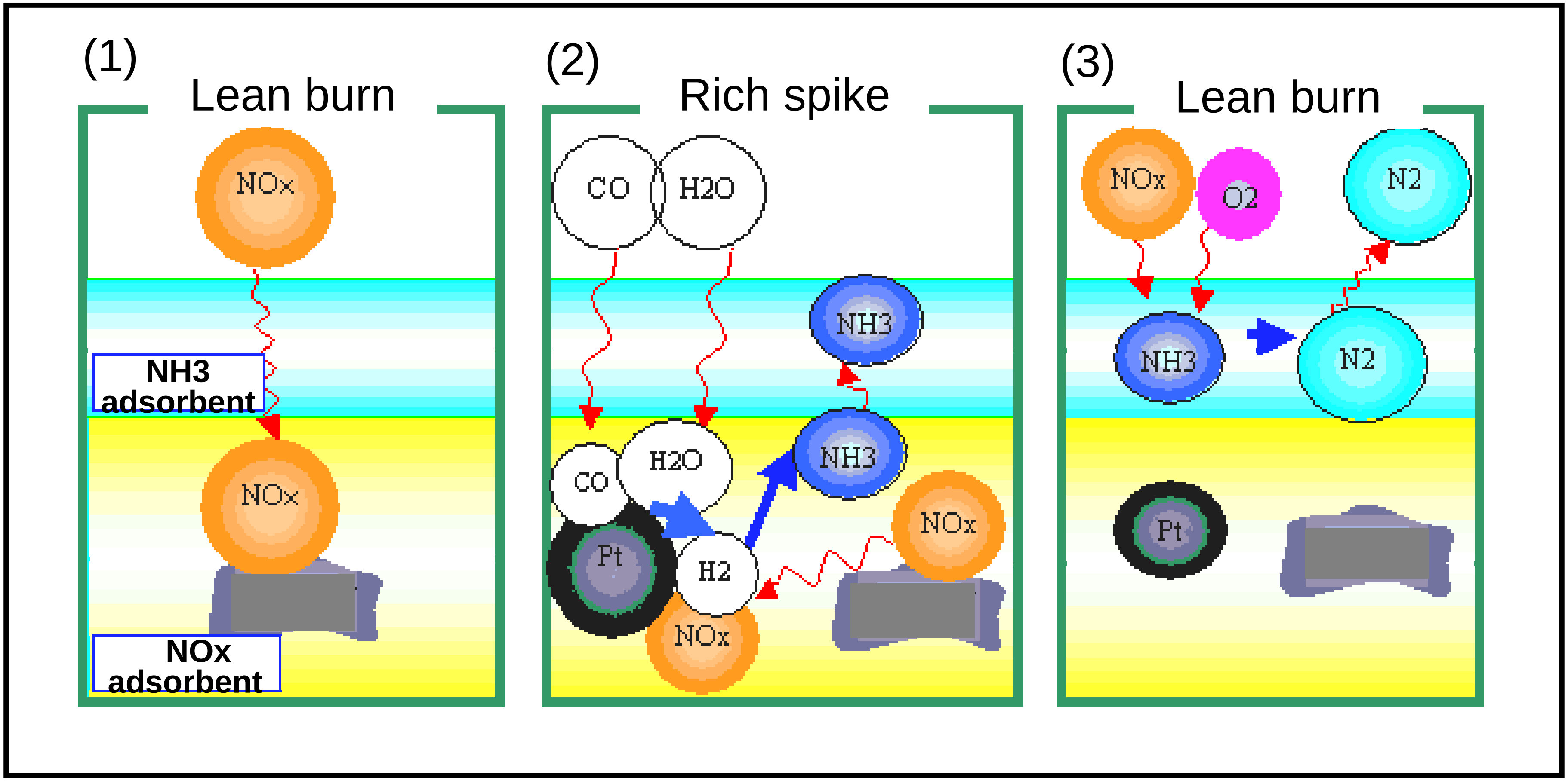


Nissan Diesel's Urea-SCR system (October 7, 2004)



O*: Active Oxygen

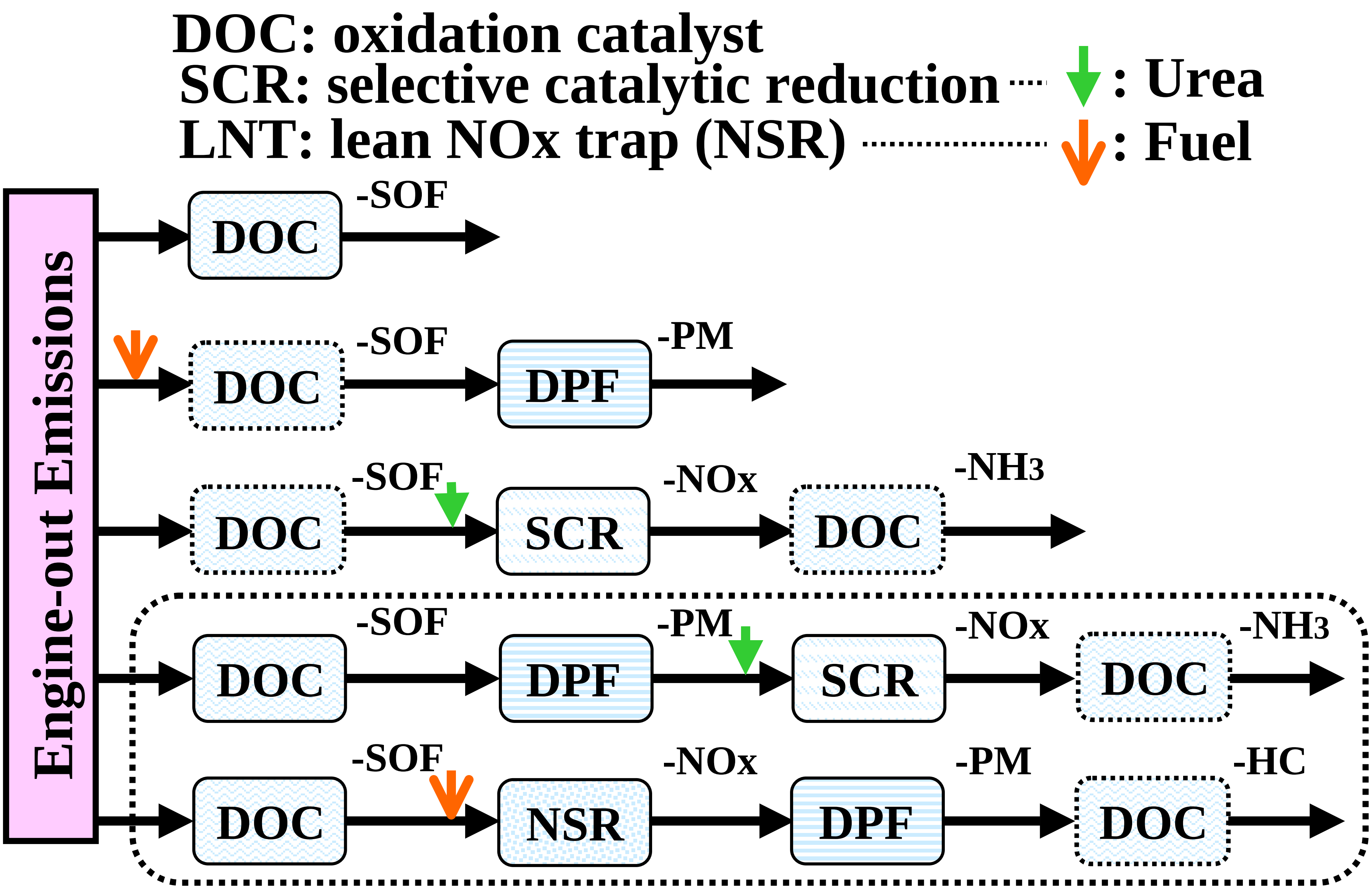
Simultaneous NOx and PM Reduction by DPNR, Toyota, 2000



Honda's New DeNOx Catalyst System Internally Generating NH3 for Diesel Passenger Cars, 2006 (to comply with the US Tier2, Bin5 in 2009)

Comparison of NO_x Storage Reduction and Urea-SCR for Diesel Vehicles

Item	NOx storage reduction	Urea-SCR
NOx conversion % (at low temperature)	50-90 (△△)	60-95 (△)
Durability (Sulfur resistance)	△ (△)	◎ (○)
Fuel penalty %	3-5 (△)	◎
Compactness	◎	△ (Zeolite:○)
Convenience	◎	△ (Urea supply)
Applications	Passenger car Light-duty Vehicle Medium-duty vehicle	Heavy-duty vehicle Medium-duty vehicle Passenger car



Various Diesel Aftertreatment Systems

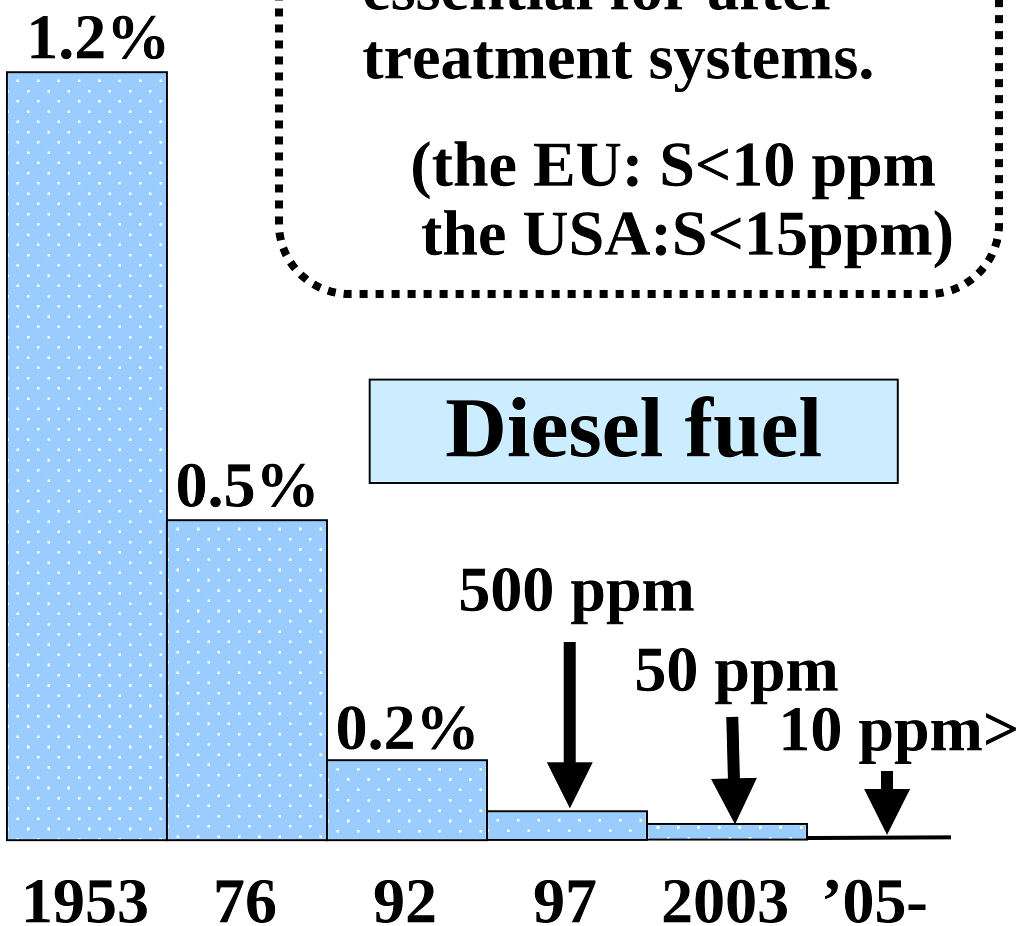
Advanced Engine Control Methods will be necessary to meet future stringent emission standards.

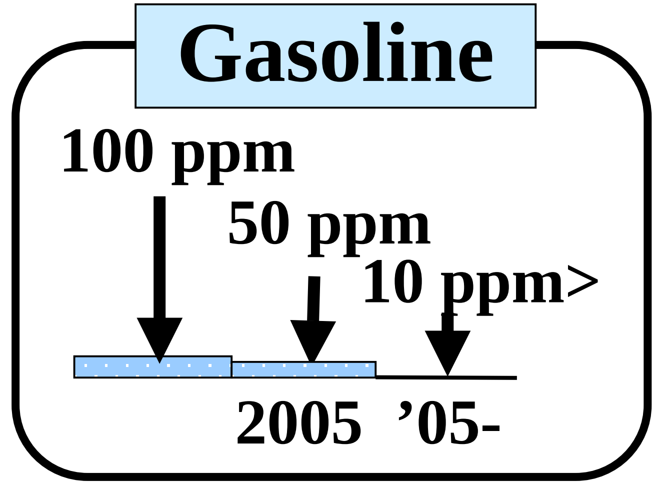
- **Limited capability of "*Map-Based Control*"**
  - ***Increased parameters for engine control**
  - ***Excessively increased maps**
  - ***Difficulty with using steady-state maps for transient conditions**
- **Introducing "*Model-Based Control*"**
  - ***Based on simplified mathematic models and/or physical models for transient conditions**
  - ***High applicability to a wide variety of engine systems**
  - ***Employing sensors and actuators**
  - ***Minimizing development time and cost**

Desulfurizing Fuels in Japan

Low sulfur fuels are essential for after-treatment systems.

(the EU: S<10 ppm
the USA:S<15ppm)





Will almost zero sulfur fuels be necessary for NSR(LNT) after 2009?

Heavy-duty Vehicle Fuel Economy Targets to be in effect (Japan, FY2015)

- **The purpose is to reduce fuel consumption and eventually CO_2 emission from heavy-duty trucks and buses.**
- **Fuel economy is evaluated based on engine test data and numerical simulation models, taking into account a variety of vehicle types, based on "the Top Runner Policy."**
- **An average improvement of 12.2% by FY2015 compared to levels in FY2002.**
- **It is expected that advanced engine and vehicle technologies will be developed to achieve the targets.**

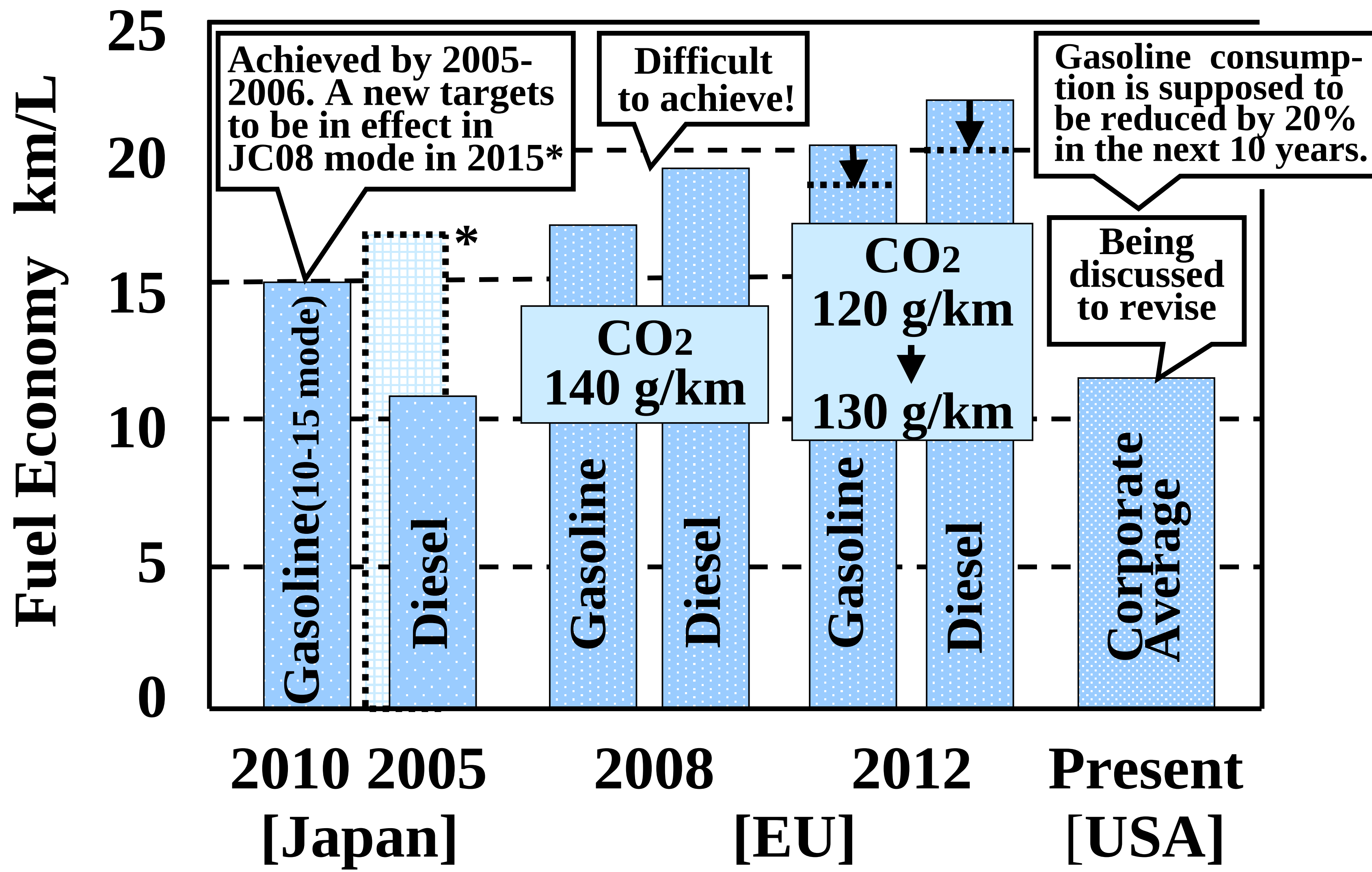
Heavy-duty Vehicle Fuel Economy Targets
(Gross Vehicle Weight>3.5 t, Japan)

< Trucks >

	2002	2015	Improve-ment
Other than tractors	6.56	7.36	12.2%
Tractors	2.67	2.93	9.7%
Overall	6.32	7.09	12.2%

< Buses >

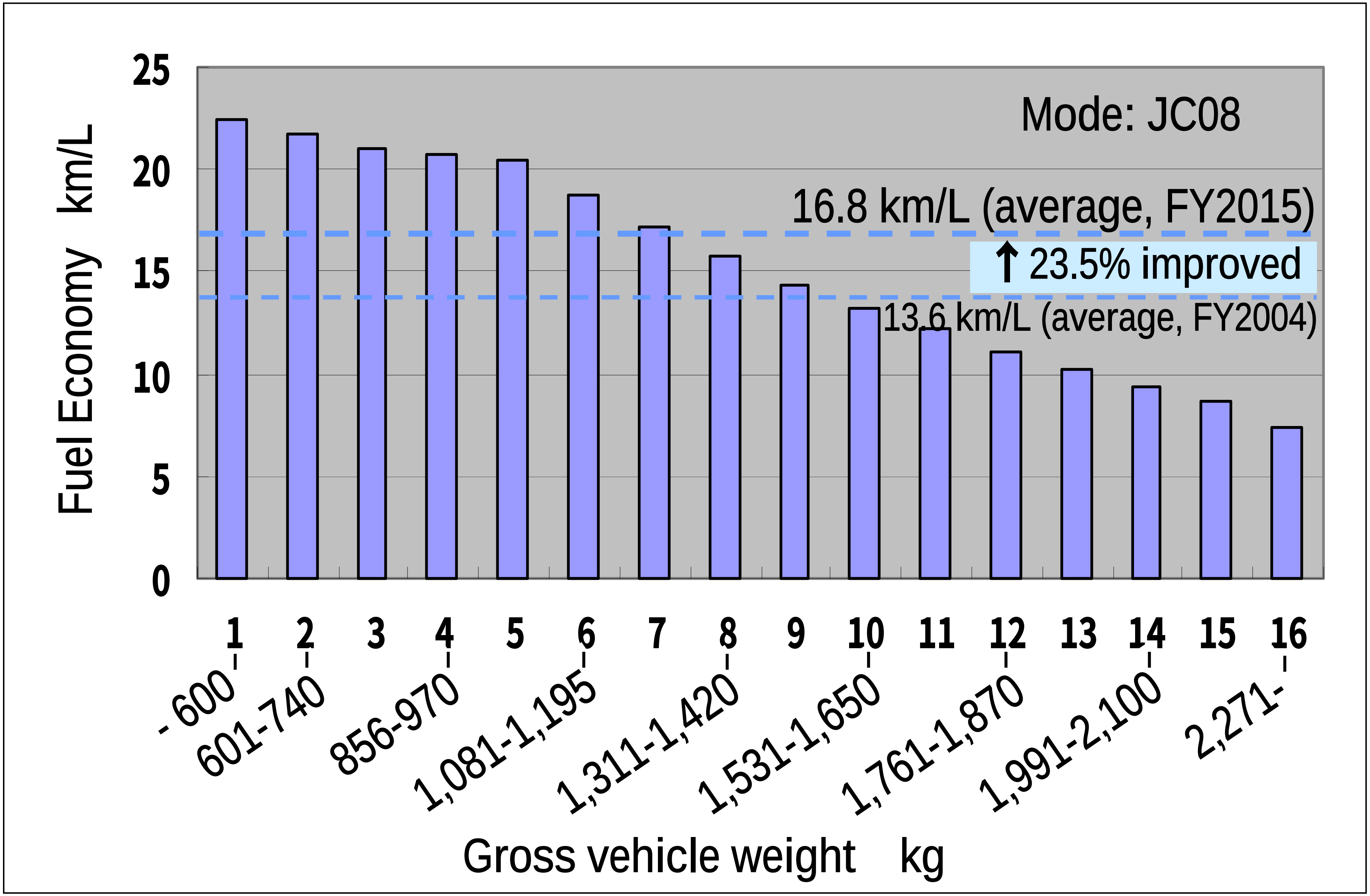
	2002	2015	Improve-ment
Transit Buses	4.51	5.01	11.1%
Ordinary Buses	6.19	6.98	12.8%
Overall	5.62	6.30	12.1%



Passenger Car Fuel Economy Standards in Japan, EU and USA

New fuel economy standards will be in effect for passenger cars and light- and medium-duty vehicles in FY2015, Japan

- The 2010 fuel economy standards has been attained five years earlier by all Japanese automakers, improving the economy by 22.8% compared to the levels in 1995.
- An average economy improvement of 23.5% will be possible compared to the levels in FY2004, based on "the Top Runner Policy."
- Engine variable mechanisms, control systems, etc. will be improved and utilized.
- Cold start fuel economy is taken into account.
- CVTs will be used as a common technology.
- Some automakers will take advantage of hybrids.



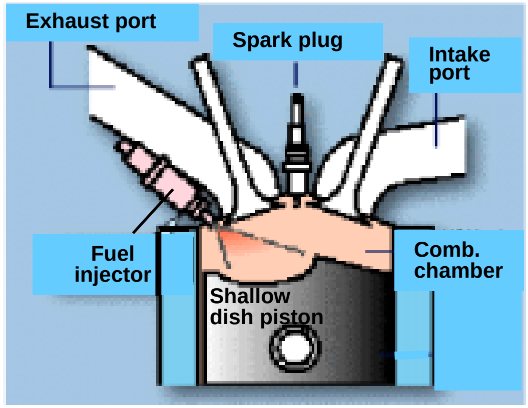
Fuel Economy Standards for Passenger Cars in Japan

Technologies for Improving Fuel Economy

Improvement ◎: 10%< ○¦5-10% □:5%>

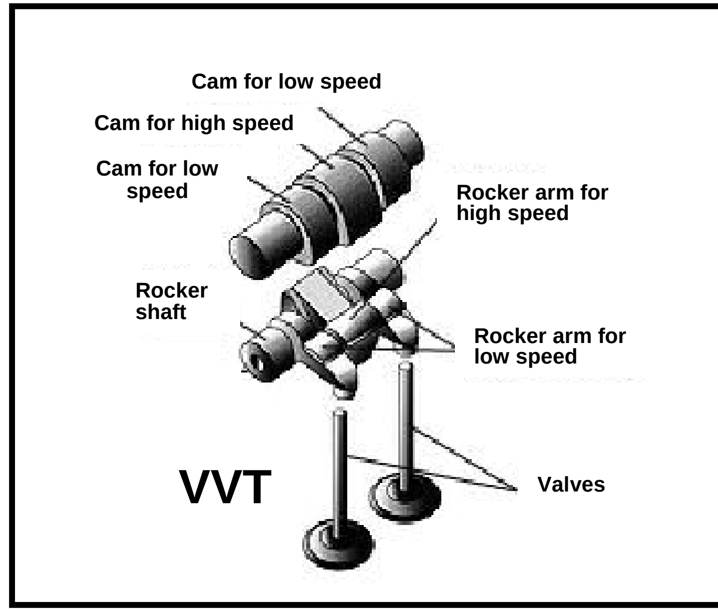
Items		Technologies
Engine	New concept	◎Direct-injection ◎Hybridization ◎Miller cycle ○Lean burn ◎Downsizing with turbocharging
	Control	○Stopping engine at idle □Precise fueling and ignition timing □Variable valve mechanism (VVM)
	Pumping loss reduction	◎Modulated displacement □Four valves □VVM
	Friction reduction	□Improving lubrication □Lightweight moving parts
Drivetrain		○CVT ○Automated MT □Lockup mechanism
Vehicle		◎Lightweight materials ◎Low air drag □Low rolling resistance tires

Mechanisms for Improving Fuel Economy in Gasoline Engines



Direct-injection Gasoline Engine

(10〜30%)



(5%〜)

CVT (5〜10%)

(percent improvement)

- In-line 4 cylinders, DOHC (4 valves)
- Intercooled turbo + supercharger
- Direct-injection (stoichiometric)
- VVT control system
- Bore×stroke: 76.5×75.6 mm
- Displacement: 1.389 L
- Compression ratio: 9.7
- Transmission: DSG
- Max. power [net]:
  125 kW (170 PS)/6,000 rpm
- Max. Torque [net]:
  240 Nm (24.5 kgfm)/1,500-4,750 rpm
- Fuel economy (10・15 Mode: 14.0km/L

VW's DI Gasoline Engine "TSI"

(An Advanced Example for downsizing the engine, 2006)

- **2.3 L, Four cylinders, Stoichiometric combustion, Compression ratio: 9.5, Injection pressure: 11.5 MPa**
- **Maximum power: 180kW (245PS) /5,000rpm**
- **Maximum: 350Nm (37.5kgfm) /2,500rpm**
- **Equivalent to a 3L engine achieving lighter weight and higher fuel economy**
- **Ultra-low emissions, 10% higher fuel economy that 2010 standard for 2WD version**

Mazda's Downsized SI Engine with Turbocharged Direct-Injection System "MZR 2.3 L DISI" (2006)

Mercedes-Benz's HCCI "DiesOtto" Engine for a Concept Car "F700 (S-Class)" (July, 2007)

■Engine (with Mild hybrid system)

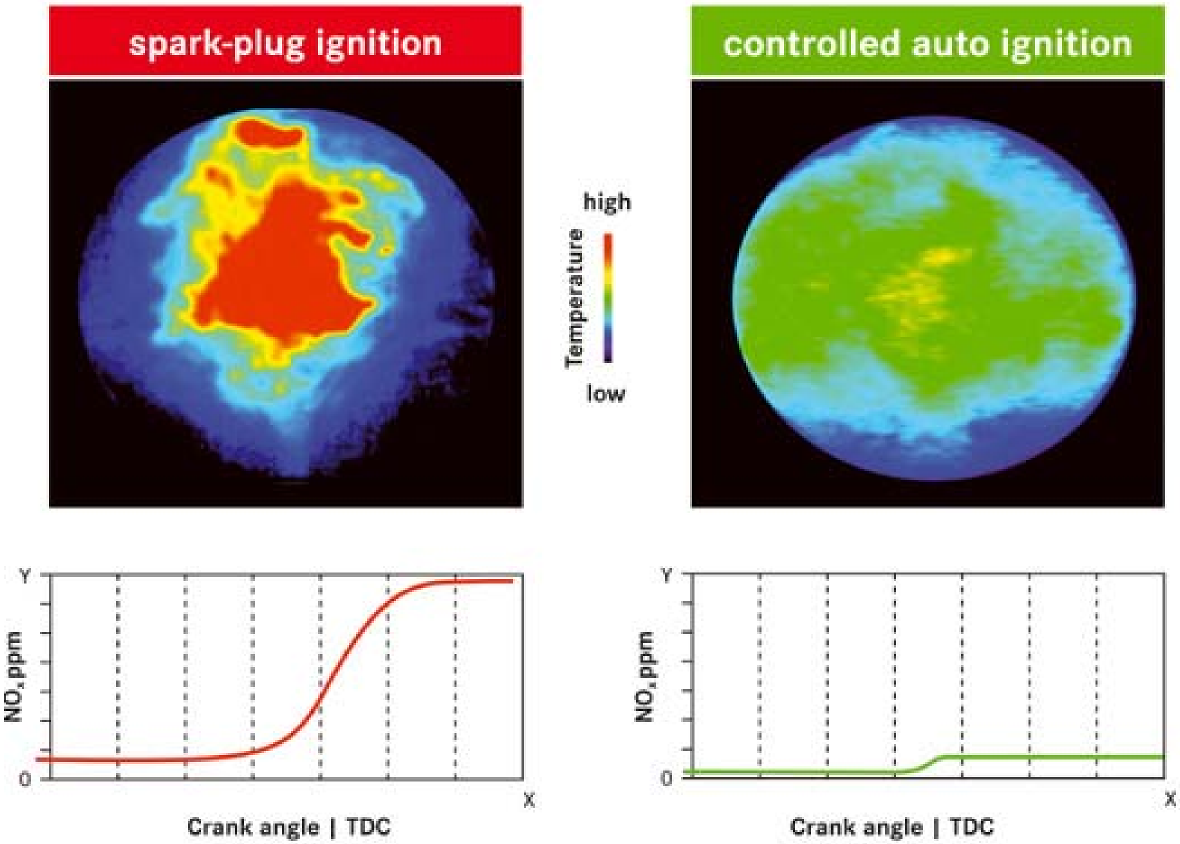
- Displacement: 1.8 L, 4 cylinders, Power: 175kW(238bhp)
- Max torque: 400 Nm (assisted by 15 kW motor)
- Fuel economy: 6 L/100 km
- HCCI
- Variable valve timing (VVT)
- Variable geometry turbocharger (VGT)
- Variable compression ratio (VCR)
- Gasoline direct-injection (GDI)
- Starter/alternator (ISA)
- Three-way catalyst

■Operational modes

(1) Stop-start at idle (Mild hybrid)

(2) Controlled autoignition at med. speed and part load

(3) Turbocharging and direct-injection with spark ignition

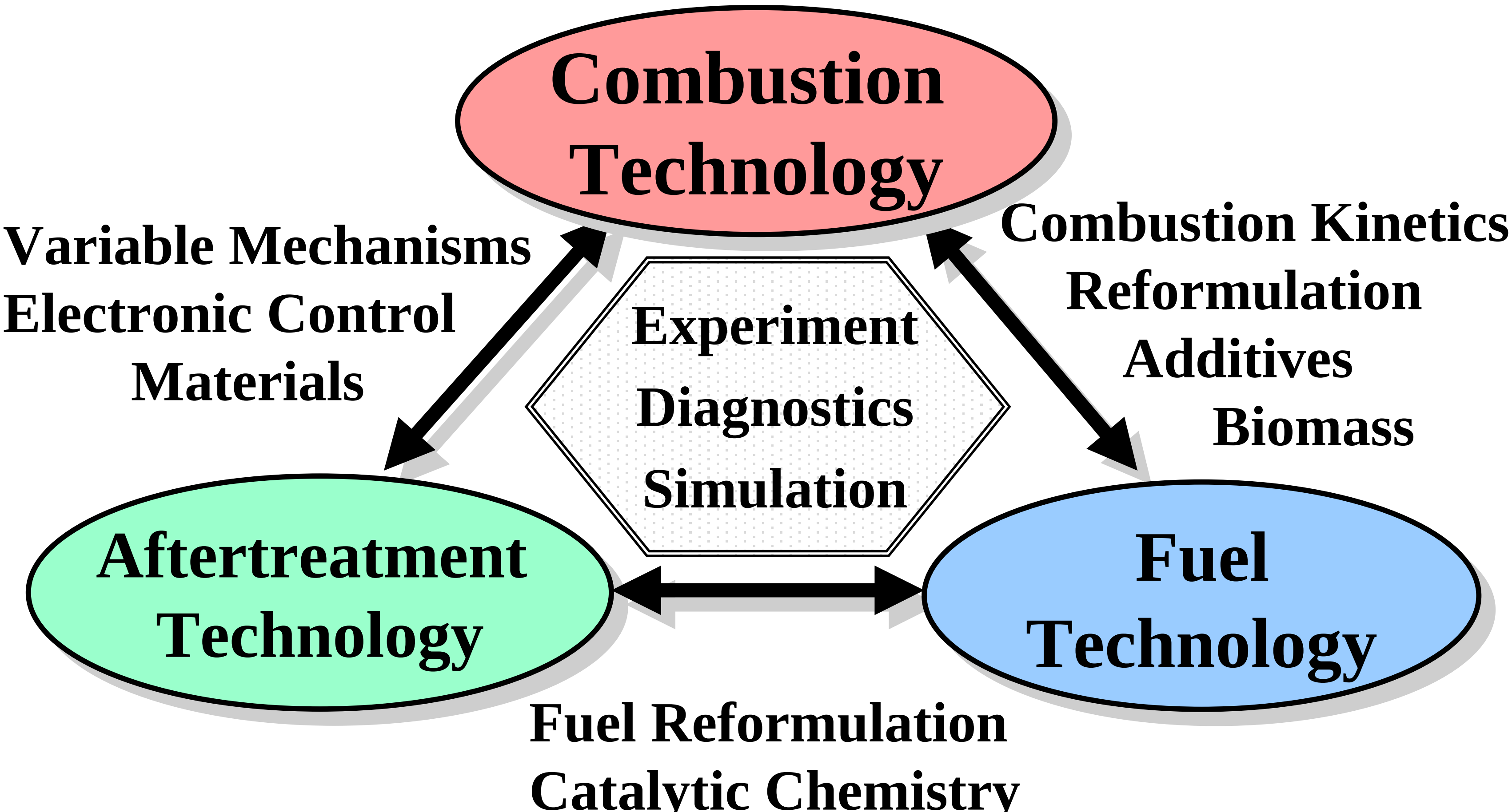


Since the air/fuel mix ignites at many points simultaneously, combustion is very even. Moreover, it results in very low emissions of nitrogen oxides. The reason for this is the homogeneous combustion at reduced and constant reaction temperatures.
Savings potential is developed in the partial load range in which engine is normally used.

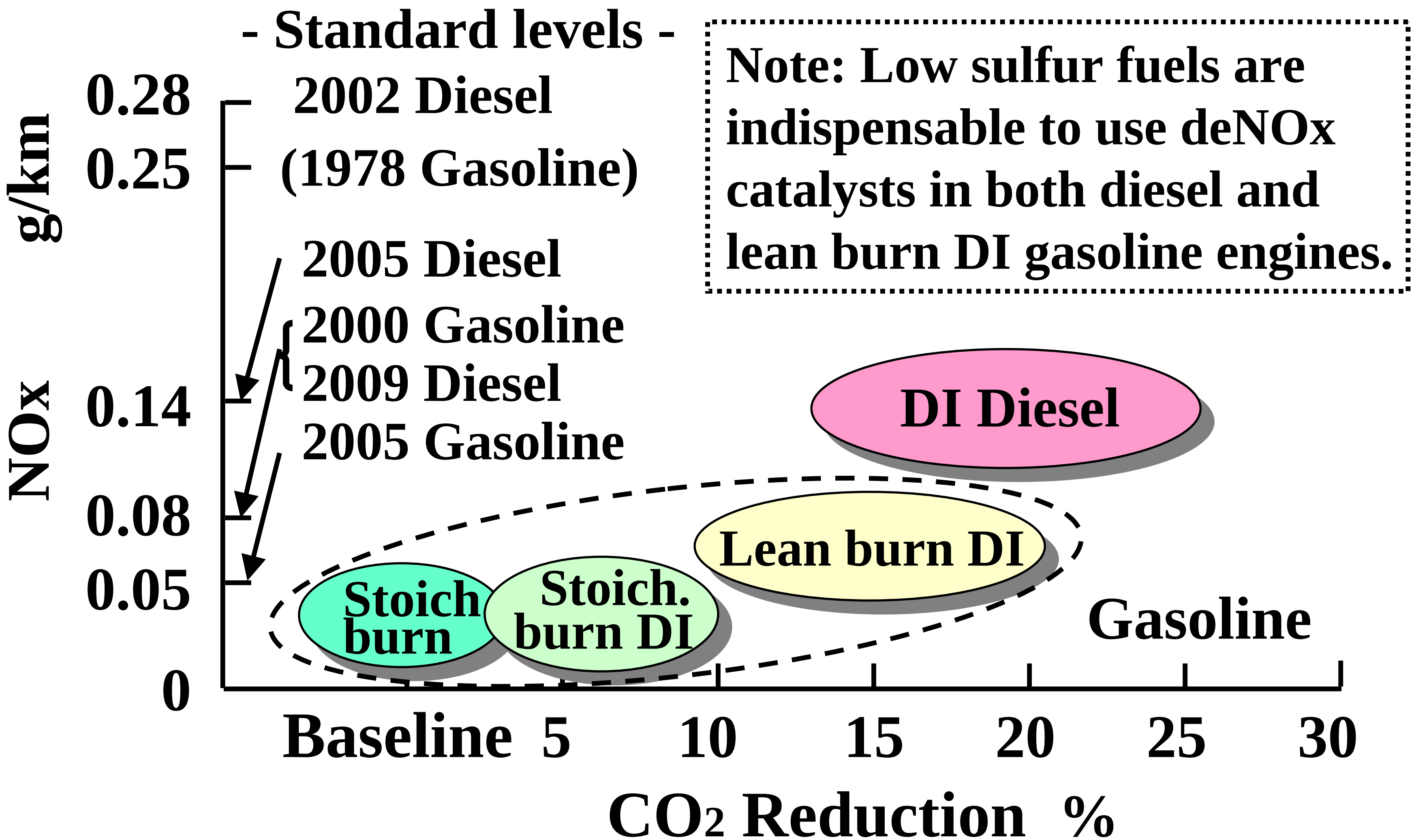
This is very different from conventional combustion using spark plugs (left), in which heat spots and temperature peaks can occur, leading to increased emission of nitrogen oxides.

Combustion in the DiesOtto Engine

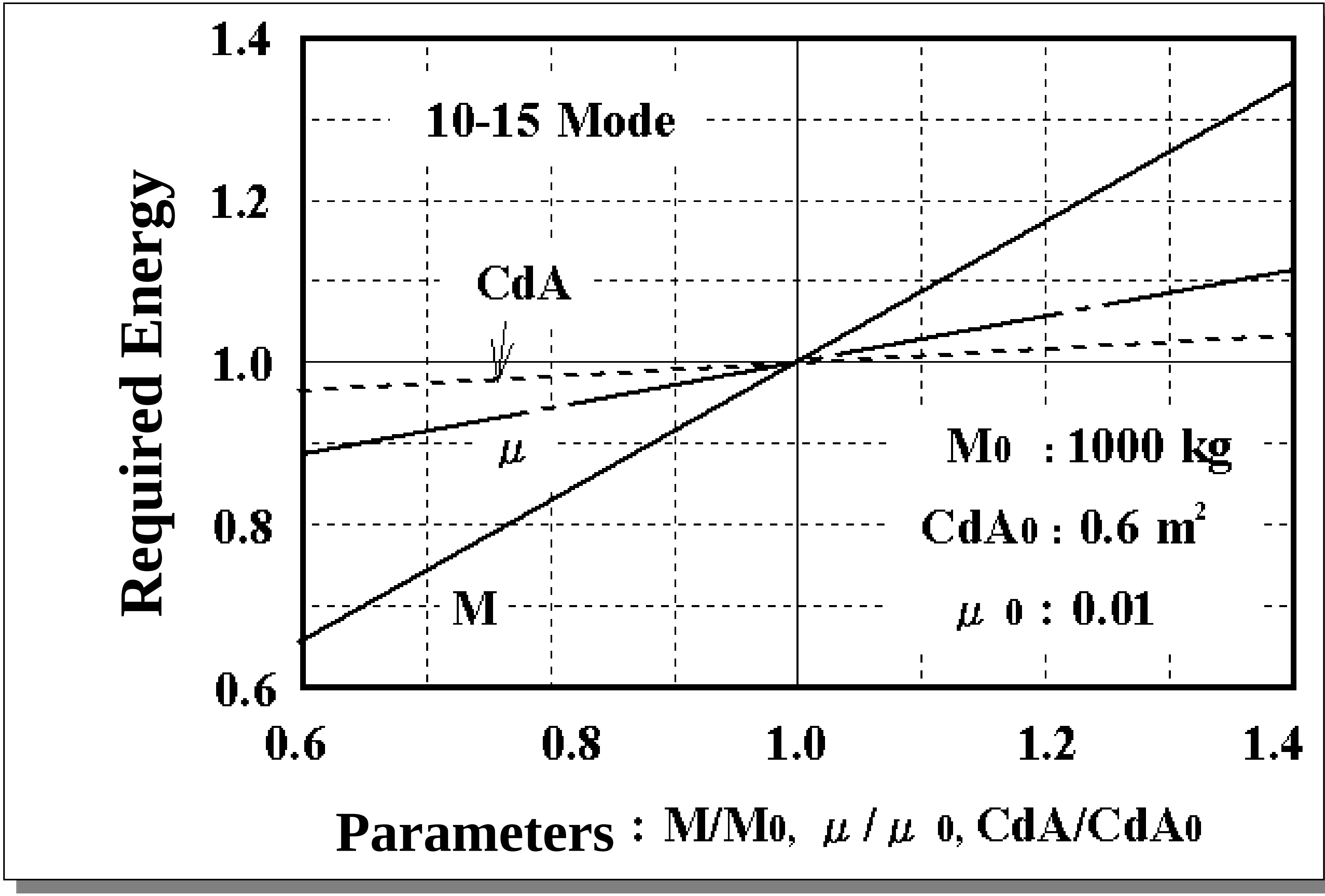
Gasoline and diesel engines will remain as the major powerplants utilizing advanced technologies for three more decades to come.



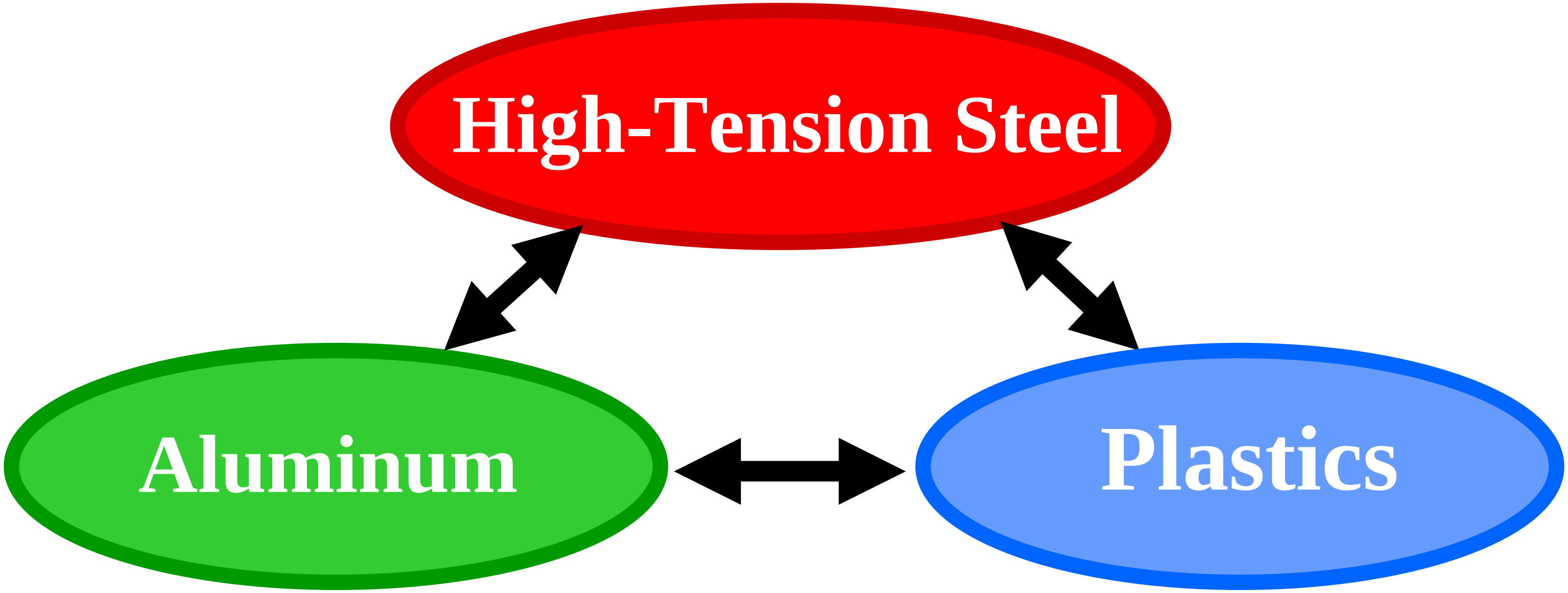
Three Key Technologies for Improving Emissions and Efficiency in SI and Diesel Engines



NOx-CO_2 Trade-offs of Gasoline and Diesel Passenger Cars



Effects of Resistance Parameters on Required Energy



- Improving fuel economy and driveability, lowering emissions and downsizing the power system
- Important issues: productivity, safety, material availability, recyclability and cost
- Proposing challenging opportunities to develop advanced technologies for lightweight vehicles safety

Three Materials for Reducing the Vehicle Weight

ULSAB-AVC: UltraLight Steel Auto Body Project - Advanced Vehicle Concept (-2002)

☆ **Participants in the consortium: 33 steel Manufacturer**

☆ **Utilization of AHSS (Advanced High Strength Steel)**
The body weight is reduced by 20-30% (2002), achieving

☆ **CO_2 of 140g/km (EU, 2008)**

☆ **Four to Five stars of collision safety are obtained based on NCAP (New Car Assessment Program)**

☆ **It is announced that very high fuel economy, safety and recycleability can be achieved at reasonable increased costs.**

Toyota's Concept Car "1/X" (Oct. 2007)

- **Body: L=3900, W=1620, H=1410 mm,**
  Wheelbase=2600 mm
  CFRP is used achieving the same space as that of "Prius" and 1/3 vehicle weight (420 kg) and twice higher fuel economy (60 km/L or 140 mpg).
- **Powertrain: 0.5L gasoline engine (FFV) with a plug-in hybrid system located under the floor for rear drive**