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

Yasuhiro Daisho
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
Developing and commercializing super clean diesel vehicles is strongly expected in 2009-2014.

Note: Engine test cycles are different.

HD Diesel NOx and PM Emissions Regulations
DeNOx catalysts are indispensable for diesel and lean burn gasoline cars. EU6 includes particle No. less than $5\times10^{11}$/km.

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.
High-Pressure Injection Systems

Piezo-type Injector for Passenger Cars

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

(Source: Bosch)
Controlling Diesel Combustion by means of Multiple-Injection
Extending Ignition delay enhances fuel-air mixing, thereby avoiding local rich zones where soot is formed.

EGR is effective to decrease burned gas temperatures and O2 concentrations, thereby reducing NOx.

(M. Potter, DEER 2006)
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

<table>
<thead>
<tr>
<th>Method</th>
<th>☐: Advantage</th>
<th>☐: Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early injection</td>
<td>☐ Fuel deposition on the cylinder wall</td>
<td>☐ Lower controllability (longer ignition delay)</td>
</tr>
<tr>
<td></td>
<td>☐ Lower controllability (longer ignition delay)</td>
<td>☐ Explosive combustion at heavy load</td>
</tr>
<tr>
<td>Late injection (MK concept)</td>
<td>☐ Lower peak pressure and pressure rise</td>
<td>☐ Deceased efficiency (High swirl mixing)</td>
</tr>
<tr>
<td>Low compress. ratio</td>
<td>☐ Increased mixing time</td>
<td>☐ Decreased efficiency</td>
</tr>
<tr>
<td>Variable valve mechanisms</td>
<td>☐ Higher controllability</td>
<td>☐ Complex mechanism</td>
</tr>
<tr>
<td></td>
<td>☐ Ensuring efficiency (Miller cycle)</td>
<td></td>
</tr>
</tbody>
</table>
Bore x Stroke: 85 x 90 mm
Fuel injection nozzle: φ0.153 mm x 5 holes

145 deg. Fuel spray

Top view

Front view

(Waseda Univ.)

A CFD Model Combined with Detailed Chemistry
Calculation results
Gas Temperatures and Fuel Droplet Dynamics
(Y. Murata, Y. Daisho, Waseda Univ.)

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

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

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

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

-30 deg ATDC

PCCI Combustion

Temperature K
400 920 1440 1960 2480 3000

Droplet diameter mm
0.0 0.031 0.061 0.092 0.122 0.153
Roles of Numerical Modeling for Engine R&D, Design and Production

< Phases >
- Understanding phenomena
- Conceptual design
- Detailed design
- New engine concepts

< Advantages >
- Reducing workload for tests
- Minimizing the overall development time and cost
- Useful CAE tools

< Developing sub-models >
- Spray model (atomization, wall interaction, mixing, etc.)
- Kinetics model (reaction data)
- Pollutants formation models
- Improving computational performance (time & capacity)

< Measurements >
- Pressures and heat release
- Visualization
- Laser diagnostics, etc.

Developing and utilizing numerical models

Validation

< Phases >

- Phases

< Advantages >

- Advantages

< Developing sub-models >

- Sub-models
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)
Simultaneous NOx and PM Reduction by DPNR, Toyota, 2000

The diagram illustrates the process of simultaneous NOx and PM reduction using DPNR technology. In the Lean Condition, NO is converted to NO2, and NO2 is oxidized to NO2 + O* in the Filter Substrate. The NOx Storage Catalyst stores NOx, and NOx Reduction occurs in the Rich Condition. Similarly, PM is captured and converted to CO2 in both conditions. O*: Active Oxygen.
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 NOx Storage Reduction and Urea-SCR for Diesel Vehicles

<table>
<thead>
<tr>
<th>Item</th>
<th>NOx storage reduction</th>
<th>Urea-SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx conversion %</td>
<td>50-90 (Zeolite: 60-95)</td>
<td>60-95 (Urea: 60-95)</td>
</tr>
<tr>
<td>(at low temperature)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>□ (□)</td>
<td>□ (□)</td>
</tr>
<tr>
<td>(Sulfur resistance)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel penalty %</td>
<td>3-5 (□)</td>
<td>□</td>
</tr>
<tr>
<td>Compactness</td>
<td>□</td>
<td>□ (Zeolite: □)</td>
</tr>
<tr>
<td>Convenience</td>
<td>□</td>
<td>□ (Urea supply)</td>
</tr>
<tr>
<td>Applications</td>
<td>Passenger car</td>
<td>Heavy-duty vehicle</td>
</tr>
<tr>
<td></td>
<td>Light-duty Vehicle</td>
<td>Medium-duty vehicle</td>
</tr>
<tr>
<td></td>
<td>Medium-duty vehicle</td>
<td>Passenger car</td>
</tr>
</tbody>
</table>
DOC: oxidation catalyst
SCR: selective catalytic reduction
LNT: lean NOx trap (NSR)

Various Diesel Aftertreatment Systems

Engine-out Emissions

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

DOC -SOF

SCR -NOx

SCR -NOx

SCR -NOx

SCR -NOx

DOC -NH3

DOC -NH3

DOC -NH3

DOC -NH3

Fuel

Urea

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
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?

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

- The purpose is to reduce fuel consumption and eventually CO2 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 >

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2015</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other than tractors</td>
<td>6.56</td>
<td>7.36</td>
<td>12.2%</td>
</tr>
<tr>
<td>Tractors</td>
<td>2.67</td>
<td>2.93</td>
<td>9.7%</td>
</tr>
<tr>
<td>Overall</td>
<td>6.32</td>
<td>7.09</td>
<td>12.2%</td>
</tr>
</tbody>
</table>

### < Buses >

<table>
<thead>
<tr>
<th></th>
<th>2002</th>
<th>2015</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Buses</td>
<td>4.51</td>
<td>5.01</td>
<td>11.1%</td>
</tr>
<tr>
<td>Ordinary Buses</td>
<td>6.19</td>
<td>6.98</td>
<td>12.8%</td>
</tr>
<tr>
<td>Overall</td>
<td>5.62</td>
<td>6.30</td>
<td>12.1%</td>
</tr>
</tbody>
</table>
Passenger Car Fuel Economy Standards in Japan, EU and USA

- **Japan**
  - 2010: Achieved by 2005-2006. A new targets to be in effect in JC08 mode in 2015*
  - Gasoline (10-15 mode): Difficult to achieve!
  - Diesel: Gasoline consumption is supposed to be reduced by 20% in the next 10 years.

- **EU**
  - 2008: CO2 140 g/km
  - 2012: CO2 130 g/km

- **USA**
  - Gasoline consumption is supposed to be reduced by 20% in the next 10 years.
  - Being discussed to revise

*Gasoline consumption is supposed to be reduced by 20% in the next 10 years.*
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

Mode: JC08

16.8 km/L (average, FY2015)

23.5% improved

13.6 km/L (average, FY2004)
# Technologies for Improving Fuel Economy

<table>
<thead>
<tr>
<th>Improvement</th>
<th>☑: 10%&lt;</th>
<th>☑ 5-10%</th>
<th>☑: 5%&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Items</strong></td>
<td><strong>Technologies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine</td>
<td>Direct-injection</td>
<td>Hybridization</td>
<td></td>
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<tr>
<td></td>
<td>Miller cycle</td>
<td>Lean burn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Downsizing with turbocharging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Stopping engine at idle</td>
<td></td>
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<tr>
<td></td>
<td>Precise fueling and ignition timing</td>
<td></td>
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<tr>
<td></td>
<td>Variable valve mechanism (VVM)</td>
<td></td>
<td></td>
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<tr>
<td>Pumping loss reduction</td>
<td>Modulated displacement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Four valves</td>
<td>VVM</td>
<td></td>
</tr>
<tr>
<td>Friction reduction</td>
<td>Improving lubrication</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Lightweight moving parts</td>
<td></td>
<td></td>
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<tr>
<td>Drivetrain</td>
<td>CVT</td>
<td></td>
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<tr>
<td></td>
<td>Automated MT</td>
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<tr>
<td></td>
<td>Lockup mechanism</td>
<td></td>
<td></td>
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<tr>
<td>Vehicle</td>
<td>Lightweight materials</td>
<td></td>
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<tr>
<td></td>
<td>Low air drag</td>
<td></td>
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<tr>
<td></td>
<td>Low rolling resistance tires</td>
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</tbody>
</table>
Mechanisms for Improving Fuel Economy in Gasoline Engines

- Direct-injection Gasoline Engine: (10〜30%)
- VVT: (5%〜)
- CVT: (5〜10%)
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)
Mazda’s Downsized SI Engine with Turbocharged Direct-Injection System “MZR 2.3 L DISI” (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 than 2010 standard for 2WD version
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
Combustion in the DiesOtto Engine

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.
Gasoline and diesel engines will remain as the major powerplants utilizing advanced technologies for three more decades to come.
NOx-CO2 Trade-offs of Gasoline and Diesel Passenger Cars

Note: Low sulfur fuels are indispensable to use deNOx catalysts in both diesel and lean burn DI gasoline engines.
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:

- High-Tension Steel
- Aluminum
- Plastics
Participants in the consortium: 33 steel Manufacturer

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

CO₂ 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