



*Further Challenges in
Automobile and Fuel Technologies
For Better Air Quality*

5th JCAP Conference Gasoline WG Report

February 22, 2007



Target of the Study

- Exhaust emission of gasoline vehicles has been reduced with automotive fuel specifications and emission regulations.
 - Responding increasing demands for emission reduction and fuel economy improvement (CO₂ reduction), we plan to study following four items:
 - ① Influence of fuel sulfur on exhaust emissions and fuel economy in long driving test
 - ② Influence of T50, T90, and aromatics on exhaust emissions through fuel matrix test
 - ③ Influence of octane number (RON) on CO₂ emission and fuel economy through engine test and fuel economy simulation
 - ④ Influence of oxygenated fuel (mainly ETBE) on vehicle exhaust emissions, fuel economy/CO₂ and materials
- Providing technical data for technology and policy discussions regarding **exhaust emissions reduction, vehicle fuel economy improvement, and comprehensive CO₂ emissions reduction** from an impartial standpoint.



Definition of Zero-Emission

What we should define “zero-emission for gasoline vehicles” in this research to clarify the potential of fuel technology to support and vitalize automobile technology?

Considering exhaust emission regulations in Japan and JCAP I study, we defined it as **“the exhaust emissions equivalent to J-ULEV*”** when we started our research.

(*) Japan Ultra Low Emission Vehicle, whose emission was 75% below the Japanese 2000 regulation.

Research Plan and Performance

Theme	2002	2003	2004	2005	2006
① Research on sulfur effect (Driving test)	2 direct injection gasoline vehicles 3 sulfur concentration levels			☆ Report	
② Research on effect of T50, T90 and aromatics (Fuel matrix test)	Preliminary study		3 MPI/SIDI vehicles 3 level fuels for each parameter		☆ Report
③ Research on effect of Octane number (Engine test and simulation)	Review existing data Procure test method		Engine tests and simulations		☆ Report
④ Research on oxygenated fuel (ETBE) > Emissions, Durability, Cold startability, influence on materials Detail consideration > Fuel matrix test	<div style="border: 1px solid black; padding: 5px; display: inline-block;"> ⇄ Plan ⇄ Performance </div>			☆ Report	☆ Report



Theme 1

Influence of Sulfur Content on fuel economy/emissions

Overview

◆ Study theme	Study influence of fuel sulfur on fuel economy, CO2 emissions and exhaust emissions using technology advanced gasoline vehicles. (long driving test)						
◆ Expected outcome	Understand influence of sulfur content on fuel economy and exhaust emissions Evaluate CO2 emissions totally regarding CO2 decrease for lean-burn direct injection vehicles achieved by reducing fuel consumption due to desulfation with fuel sulfur decrease as well as CO2 increase resulted from reduction of sulfur content of fuel at refinery.						
◆ Contents	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; padding: 5px;">Test</th> <th style="width: 50%; padding: 5px;">Test fuel and vehicle</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Exhaust emission measurement</td> <td style="padding: 5px;">Conducted as part of driving test</td> </tr> <tr> <td style="padding: 5px;">Driving test</td> <td style="padding: 5px;">Test fuel : Sulfur content level 3 Test vehicle : 2 models of SIDI (lean-burn direct injection vehicle) Exhaust emissions : 75% reduction from 2000 regulations</td> </tr> </tbody> </table>	Test	Test fuel and vehicle	Exhaust emission measurement	Conducted as part of driving test	Driving test	Test fuel : Sulfur content level 3 Test vehicle : 2 models of SIDI (lean-burn direct injection vehicle) Exhaust emissions : 75% reduction from 2000 regulations
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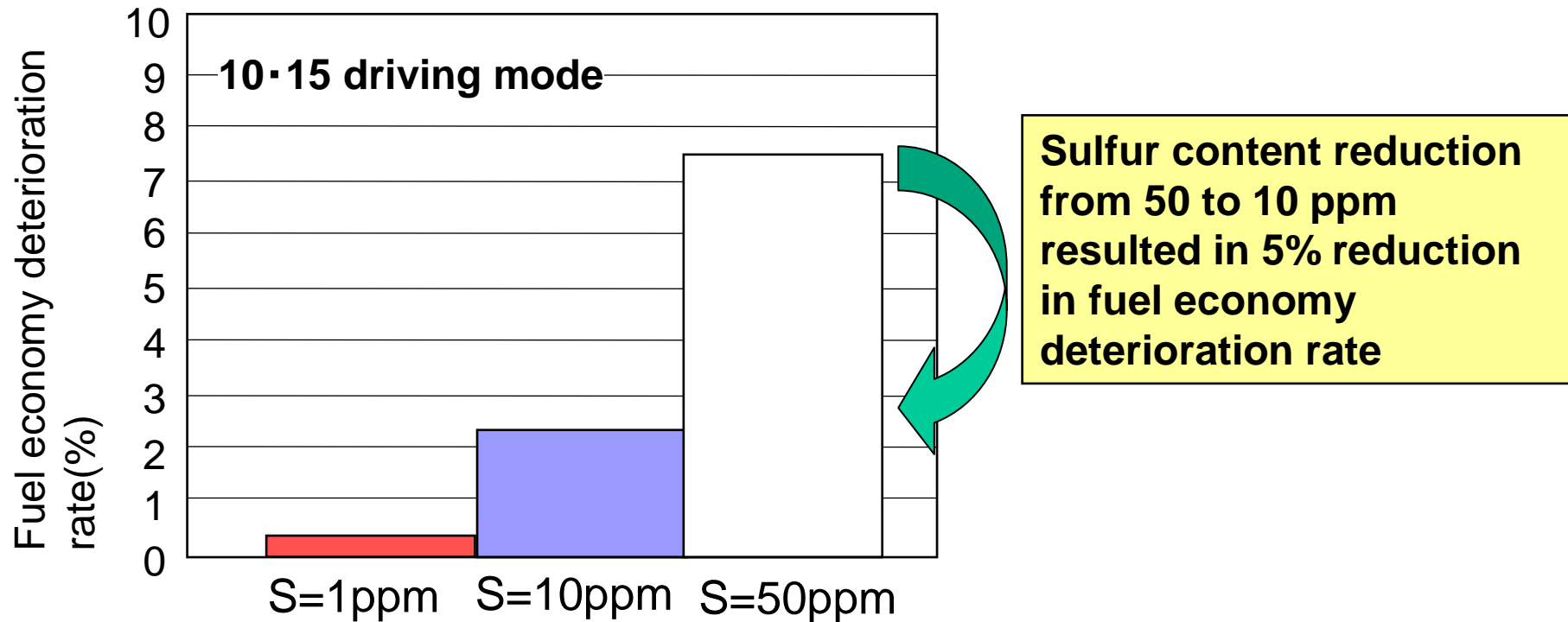
Phase1 (FY2003): Lean-Burn SIDI/Vehicle A

Influence of Desulfation of NOx on Fuel Economy

Exhaust emissions: J-ULEV levels

Desulfation frequency

:Decided to satisfy 10·15 and 11 mode combined emissions



Fuel economy
deterioration rate = 1 -

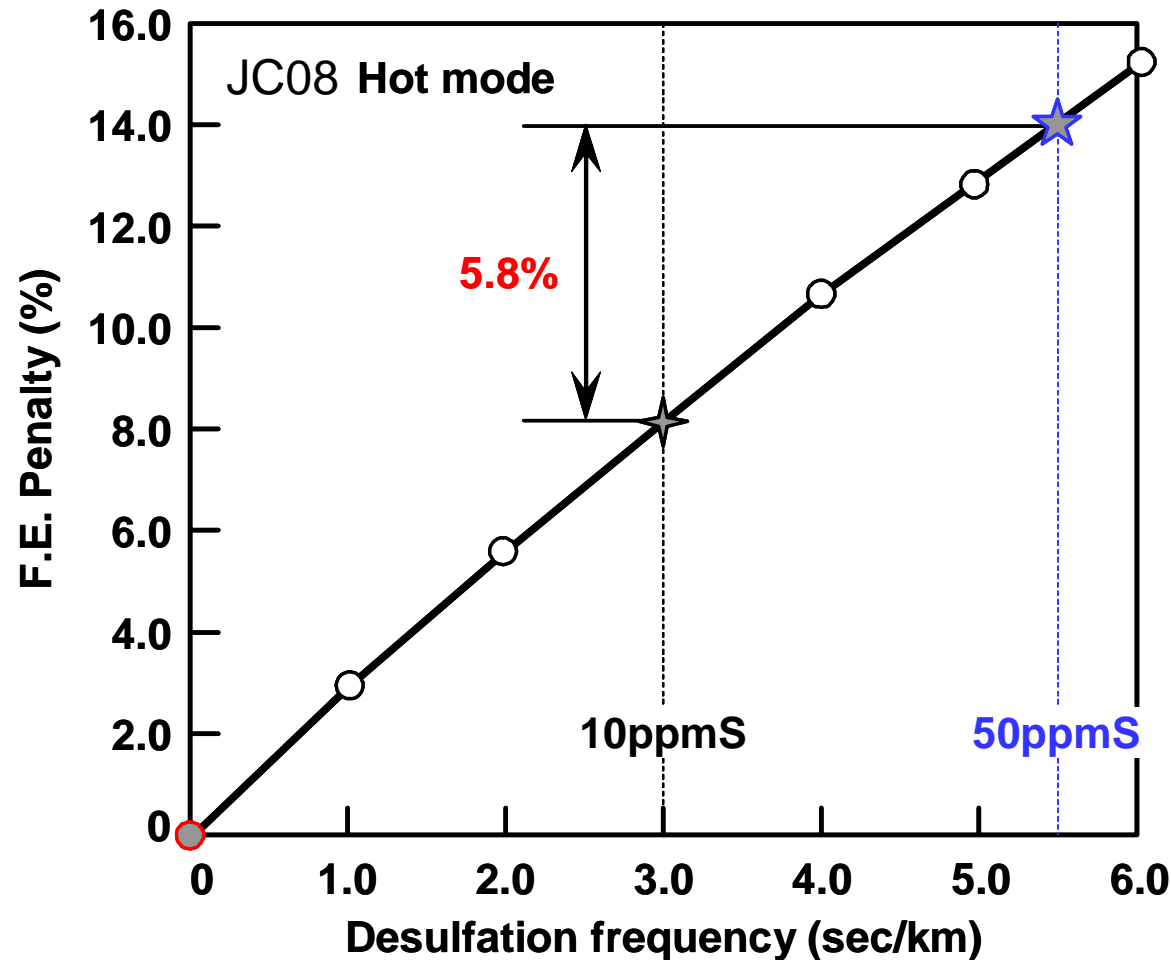
Average fuel economy with desulfation
fitted on each sulfur criterion

Fuel economy without desulfation



Phase 2 (FY2004): Lean-Burn SIDI/Vehicle B

Influence of Desulfation of NOx on Fuel Economy



Exhaust emissions
:J-ULEV levels

Desulfation frequency
:decided to satisfy JC08
hot and cold combined
emissions

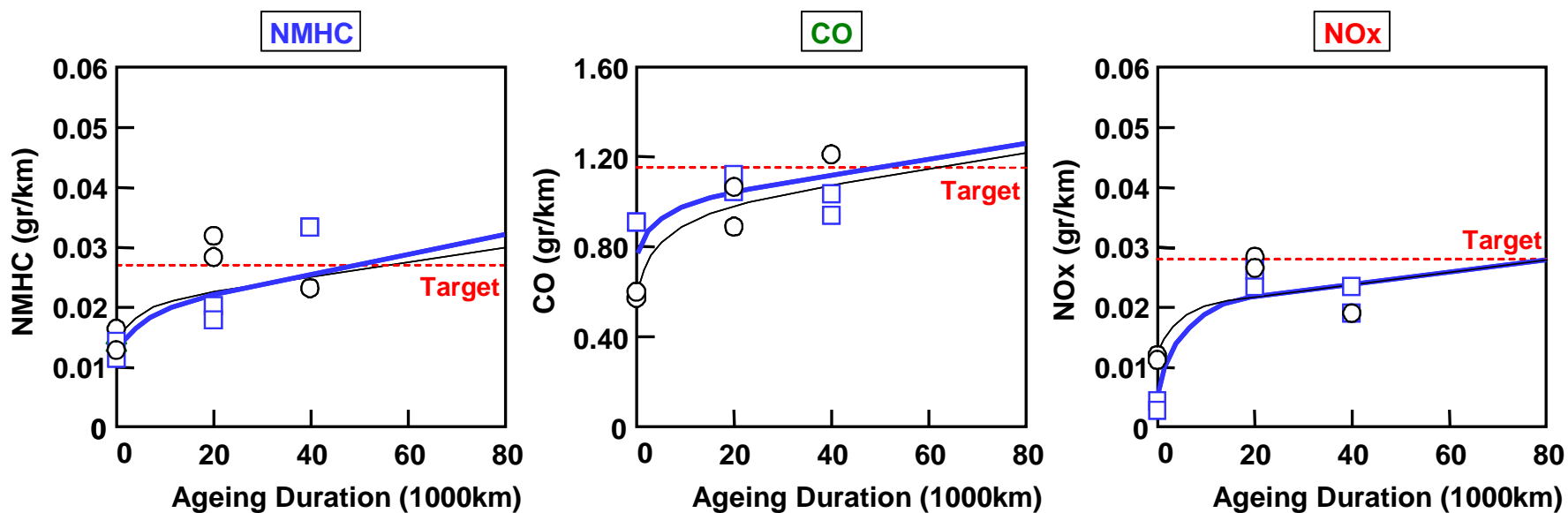
Sulfur reduction from 50 to 10 ppm resulted in 5.8% reduction in fuel economy deterioration rate



Phase 2 (FY2004): Lean-Burn SIDI/Vehicle B

Sulfur Concentration and Exhaust Emissions Measurement Results in Mileage Accumulation Test

J-ULEV equivalent emission standards can be met with regeneration control according to sulfur concentration.



—○— S10ppm, Control : S10ppm
—□— S50ppm, Control : S50ppm

- Evaluated with exhaust emission levels after 40,000km driving (JC08 Cold and Hot combined)
- Data at 20,000km aging are reference values.



Theme 1

Influence of Sulfur – Mileage Accumulation Test

Summary

Vehicle A	Phase 1 (FY 2003)
	<ul style="list-style-type: none">▪ When sulfur content of fuel was reduced from 50 to 10 ppm, difference in fuel economy on 10.15-mode basis was 5%. (Result was provided to CO2 evaluation.)
Vehicle B	Phase 2 (FY 2004)
	<ul style="list-style-type: none">▪ When sulfur content of fuel was reduced from 50 to 10 ppm, difference in fuel economy on JC08 Hot-mode basis was 5.8%.



Theme 2

Fuel Matrix Test for T50, T90, and Aromatics

Overview

◆ Study theme	Study influence of fuel properties of T50, T90, and aromatics on exhaust emission using advanced gasoline vehicles. (Fuel matrix test)							
◆ Expected outcome	<ul style="list-style-type: none"> ▪ Comprehend exhaust emission levels of the most advanced vehicles ▪ Identify fuel properties affecting emissions and to comprehend the degree of influence. 							
◆ Contents	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; text-align: center;">Test</th> <th style="width: 50%; text-align: center;">Fuel and vehicle</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">Exhaust emissions measurement</td> <td>Conducted as part of fuel matrix test</td> </tr> <tr> <td style="text-align: center;">Fuel matrix test</td> <td> Test fuel: 3 types of fuel (aromatics, T50 and T90), three standards for each specification Test vehicle: 3 MPI models, 3 SIDI models (including lean-burn model) </td> </tr> </tbody> </table>		Test	Fuel and vehicle	Exhaust emissions measurement	Conducted as part of fuel matrix test	Fuel matrix test	Test fuel: 3 types of fuel (aromatics, T50 and T90), three standards for each specification Test vehicle: 3 MPI models, 3 SIDI models (including lean-burn model)
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Theme 2

Fuel Matrix Test for T50, T90, and Aromatics

Summary

◆ Outcome 1	Phase 1 (FY2002)
	<ul style="list-style-type: none">▪ Conducted preliminary tests by using J-ULEV equivalent vehicles and evaluated exhaust emissions .▪ Established test procedures.
◆ Outcome 2	Phase 2 (FY2003 to 2005)
	<ul style="list-style-type: none">▪ No concern about emission level from J-ULEV equivalent vehicles with current control range of T50, T90 and aromatics in market.▪ Relationship/correlation was observed between aromatics and CO2 (fuel economy).



Theme 3

Octane number-Engine Test and Simulation

Overview

◆ Study theme	Identify desirable octane number to reduce CO2 emissions								
◆ Expected outcome	Identify sensitivity of fuel economy to optimum octane number to determine total CO2 emissions from all sources ranging from refineries to vehicle engines (Judged by CO2 evaluation)								
◆ Contents	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; text-align: center; padding: 5px;">Test</td> <td style="text-align: center; padding: 5px;">Fuel and engine</td> </tr> <tr> <td style="text-align: center; padding: 5px;">Review existing data</td> <td style="padding: 5px;"></td> </tr> <tr> <td style="text-align: center; padding: 5px;">Fuel economy characteristics of engine</td> <td style="padding: 5px;"> Fuel: Octane number (RON) 90-100 Engine <ul style="list-style-type: none"> ▪ Commercially available engines, 3 MPI models ▪ Compression ratio 3 levels; base and base ± 1 </td> </tr> <tr> <td colspan="2" style="text-align: center; padding: 5px;">Fuel economy characteristics of vehicle (Fuel economy simulation /MT vehicle)</td> </tr> </table>	Test	Fuel and engine	Review existing data		Fuel economy characteristics of engine	Fuel: Octane number (RON) 90-100 Engine <ul style="list-style-type: none"> ▪ Commercially available engines, 3 MPI models ▪ Compression ratio 3 levels; base and base ± 1 	Fuel economy characteristics of vehicle (Fuel economy simulation /MT vehicle)	
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Fuel economy characteristics of vehicle (Fuel economy simulation /MT vehicle)									



Engine Test and Vehicle Fuel Economy Simulation

Step 1

- Confirm validity of the research method

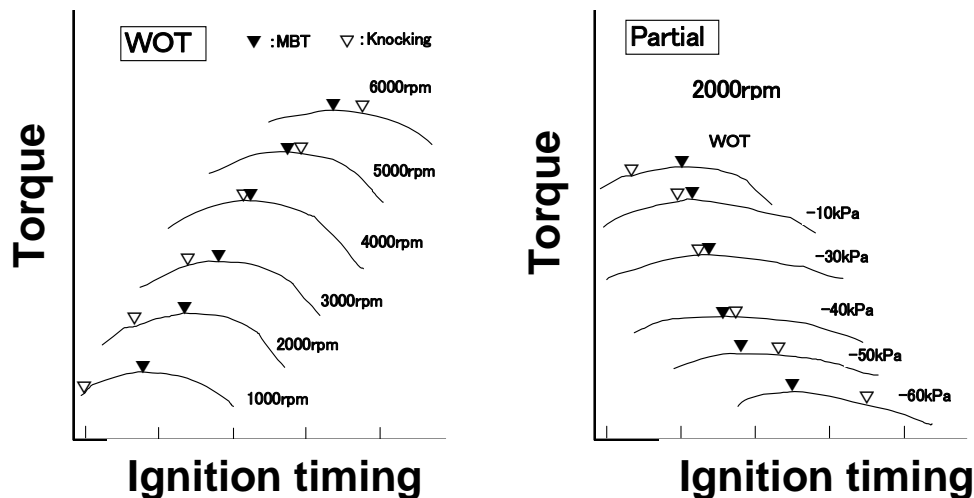
Step 2

- Conduct engine performance test with various octane fuels at each compression ratio.
- Generate **the mapping data** which based on ignition timing and torque characteristics.

Step 3

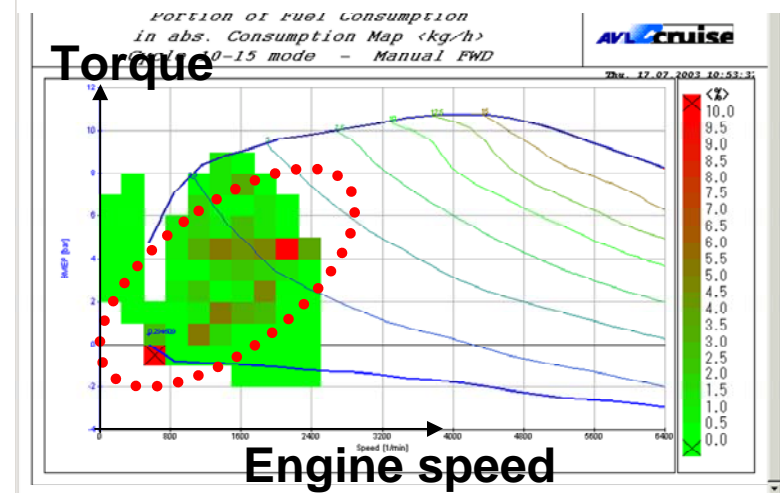
- Simulate **the vehicle fuel economy** with following assumption.
 - ① MT (manual transmission) vehicle
 - ② Difference in compression ratio is 0.35 between 90 and 95RON
 - ③ Improvement in acceleration performance is converted to improve fuel economy.

Mapping data (MBT* & Knocking characteristics)



(*) Minimum Advance for Best Torque

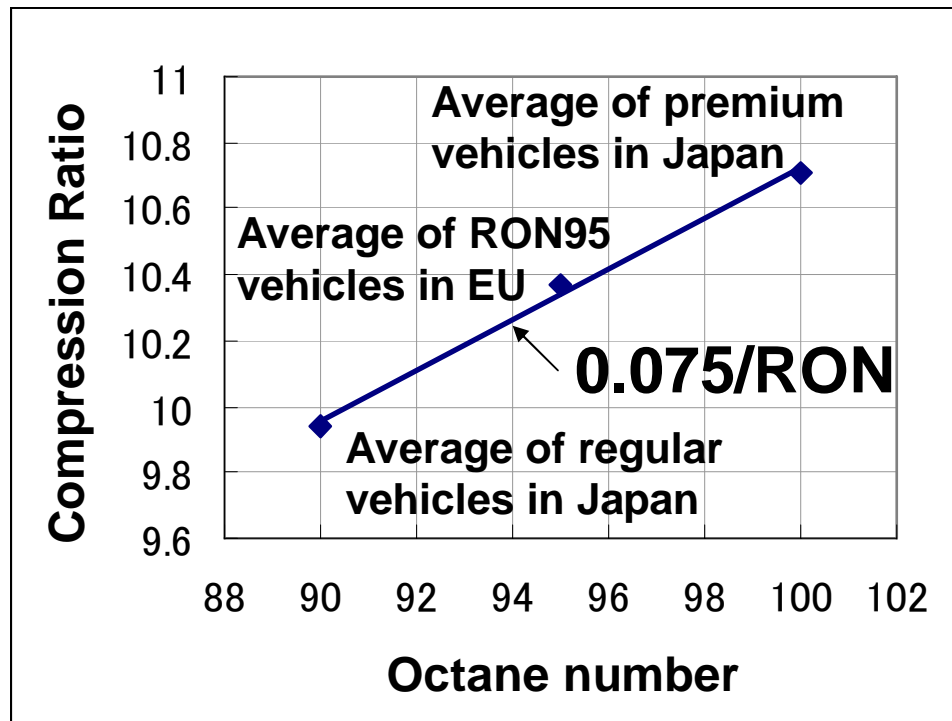
Fuel economy simulation (Schematic)



Compression Ratio at Vehicle Fuel Economy Simulation

- ① As a result of the meetings with JAMA member companies, the improvement in compression ratio per 1 RON was proved to be **0.075/RON**.
(In the range between 90 and 97RON)
- ② As a result of the investigation on average compression ratio of in-use vehicles, the difference in compression ratio per 1 RON was proved to be 0.075/RON, which is approximately consistent with the above value.

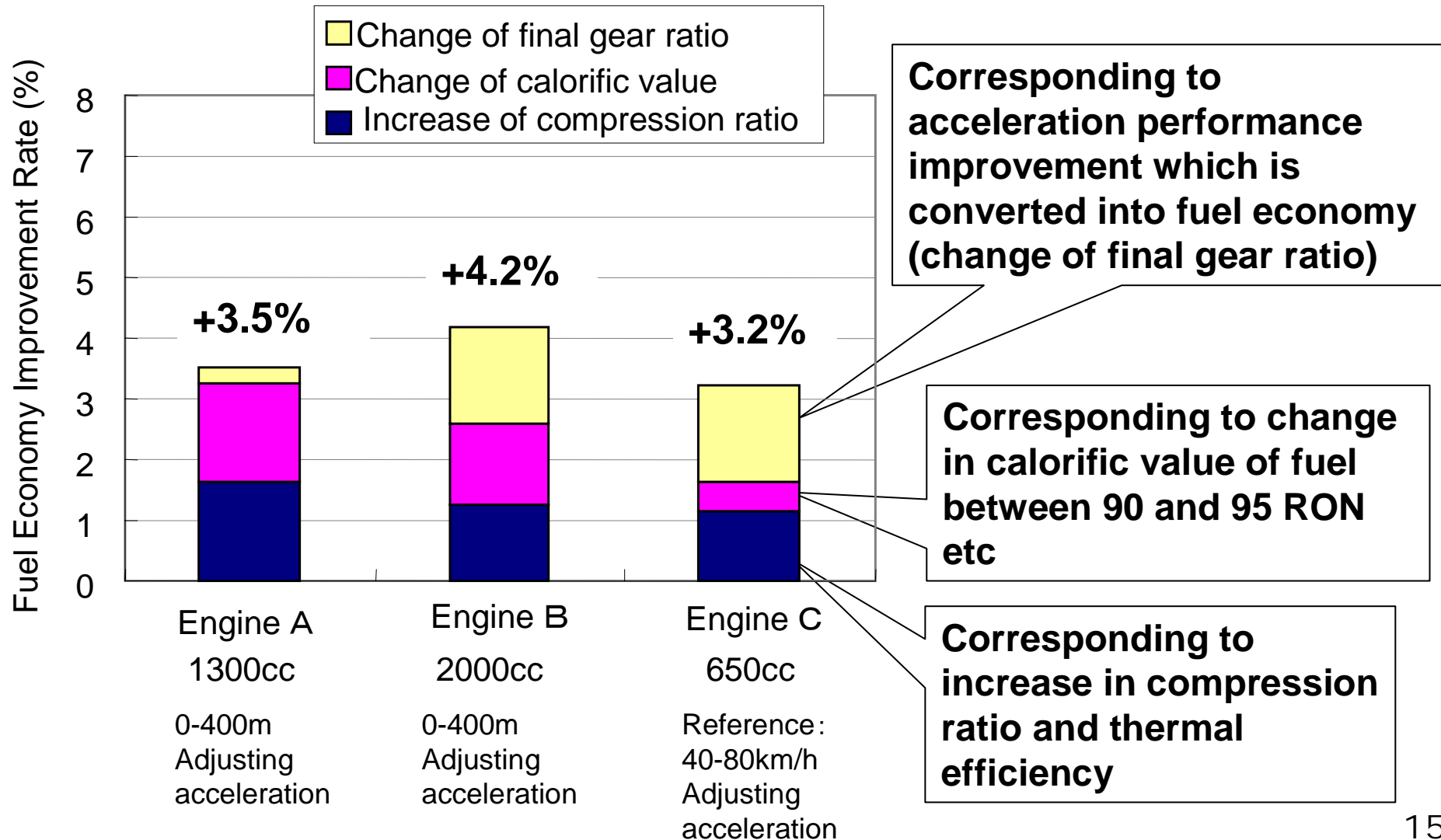
→ Set the difference in compression ratio as 0.35 when octane number is changed from RON90 to RON95



Data provided by JAMA
(EU research data is the data of 20 European car manufactures provided by JAMA.)

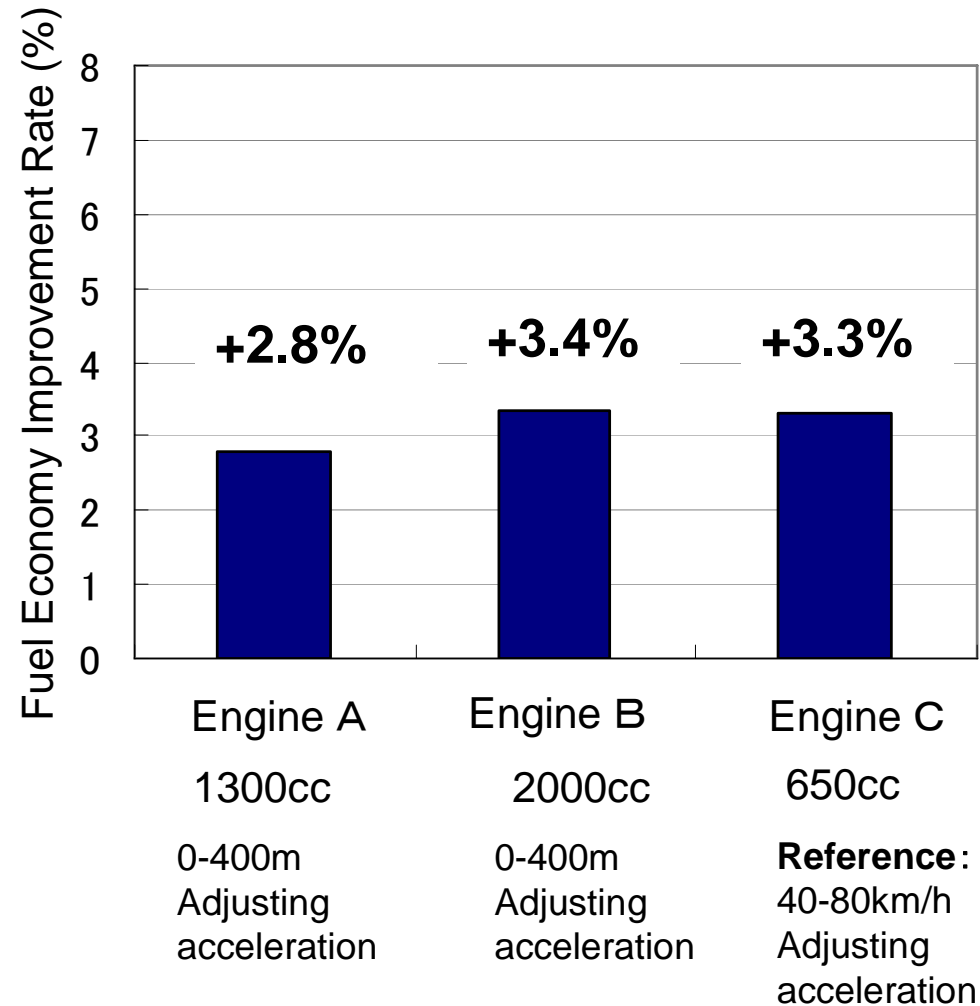
Effects of Parameters on Fuel Economy (1)

- Contribution of each parameter (compression ratio, fuel, and final gear ratio) to fuel economy (km/L) improvement



Effects of Parameters on Fuel Economy (2)

• Fuel economy (km/MJ) improvement rate





Theme 3

Octane Number – Engine Test and Simulation

Summary

	<p>Vehicle side improvement between RON90 and 95 on fuel economy</p> <ul style="list-style-type: none">· In volume basis (km/L), 3.21% to 4.15%· In energy basis (km/MJ), 2.80% to 3.35% <p>(These values were provided for CO2 evaluation as a result of FY2004 research)</p>
◆ Outcome	<p>Contribution of each parameter to fuel economy improvement</p> <ul style="list-style-type: none">a) Contribution of compression ratio: <u>1.15-1.62%</u> → Approximately equal to theoretical figure (1.1%)b) Contribution of fuel properties: <u>0.43-1.63%</u> → Energy density and carbon-hydrogen ratioc) Contribution of conversion of acceleration performance into fuel economy: <u>0.26-1.61%</u>



Theme 4-1

Evaluation of Influence of ETBE Blended Fuel

Overview

◆ Study theme	Study influence of oxygenated fuel on materials and exhaust emissions (Evaluation of effect of ETBE blended gasoline)																			
◆ Expected outcome	Confirm influence of ETBE 8% blended fuel on commercially available vehicles																			
◆ Contents	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 5%;"></th> <th style="width: 45%;">Evaluation test</th> <th style="width: 20%;">Fuel</th> <th style="width: 30%;">Vehicle</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">1</td> <td style="text-align: center;">Exhaust emissions (including unregulated substances)</td> <td rowspan="4" style="text-align: center; vertical-align: middle;">ETBE 0% ETBE 8% ETBE 17%</td> <td style="text-align: center;">4 (6 motorcycles)</td> </tr> <tr> <td style="text-align: center;">2</td> <td style="text-align: center;">Durability, tail pipe and evaporative emissions</td> <td style="text-align: center;">2</td> </tr> <tr> <td style="text-align: center;">3</td> <td style="text-align: center;">Low temperature startability</td> <td style="text-align: center;">2</td> </tr> <tr> <td style="text-align: center;">4</td> <td style="text-align: center;">Material test (Metal, plastic, & rubber)</td> <td style="text-align: center;">Rig test</td> </tr> </tbody> </table>				Evaluation test	Fuel	Vehicle	1	Exhaust emissions (including unregulated substances)	ETBE 0% ETBE 8% ETBE 17%	4 (6 motorcycles)	2	Durability, tail pipe and evaporative emissions	2	3	Low temperature startability	2	4	Material test (Metal, plastic, & rubber)	Rig test
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2	Durability, tail pipe and evaporative emissions		2																	
3	Low temperature startability		2																	
4	Material test (Metal, plastic, & rubber)		Rig test																	

ETBE 8%: Correspond to the upper limit of oxygen content (1.3wt%). When actually produced in refinery, upper limit will be 7% because of control range.



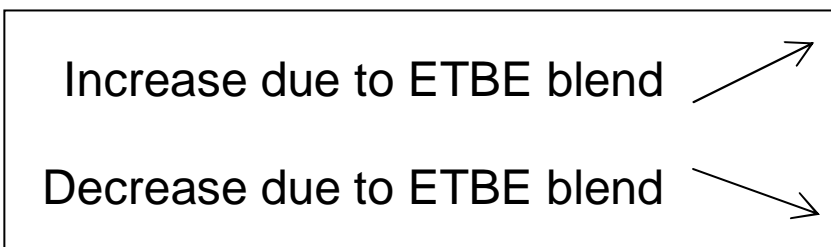
Summary of Exhaust Emissions Test Results for Passenger Cars and Mini-Vehicles

Comparison between ETBE 0% and 8%

	Vehicle type	Fuel supply system	Catalyst	Knock sensor / Feed back	CO	NMHC	NOx	CO ₂	Fuel economy
J2GVI	Passenger car	MPI	Three-way catalyst	Yes / Yes				↘	
J2GVJ	Mini-vehicle								↘
J2GVK	Passenger car	SIDI							↘
J2GVL	Mini-vehicle	MPI							↘

* No evident change was observed where arrow is not shown

* Arrow indicates that increase or decrease was observed



Summary of Analysis of Aldehydes for Passenger Cars and Mini-Vehicles

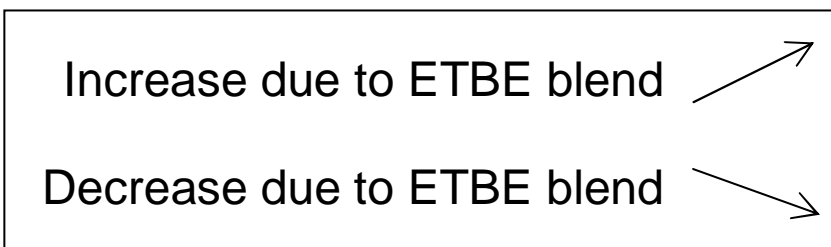
Comparison between ETBE 0% and 8%

※ below quantitative detection limit

	Vehicle type	Fuel supply system	Catalyst	Knock sensor / Feed back	Form-aldehydes	Acet-aldehydes	Acr-aldehydes
J2GVI	Passenger car	MPI	Three-way catalyst	Yes/Yes	↘	※ ↗	
J2GVJ	Mini-vehicle				※ ↗		
J2GVK	Passenger car	SIDI					
J2GVL	Mini-vehicle	MPI			※ ↗		

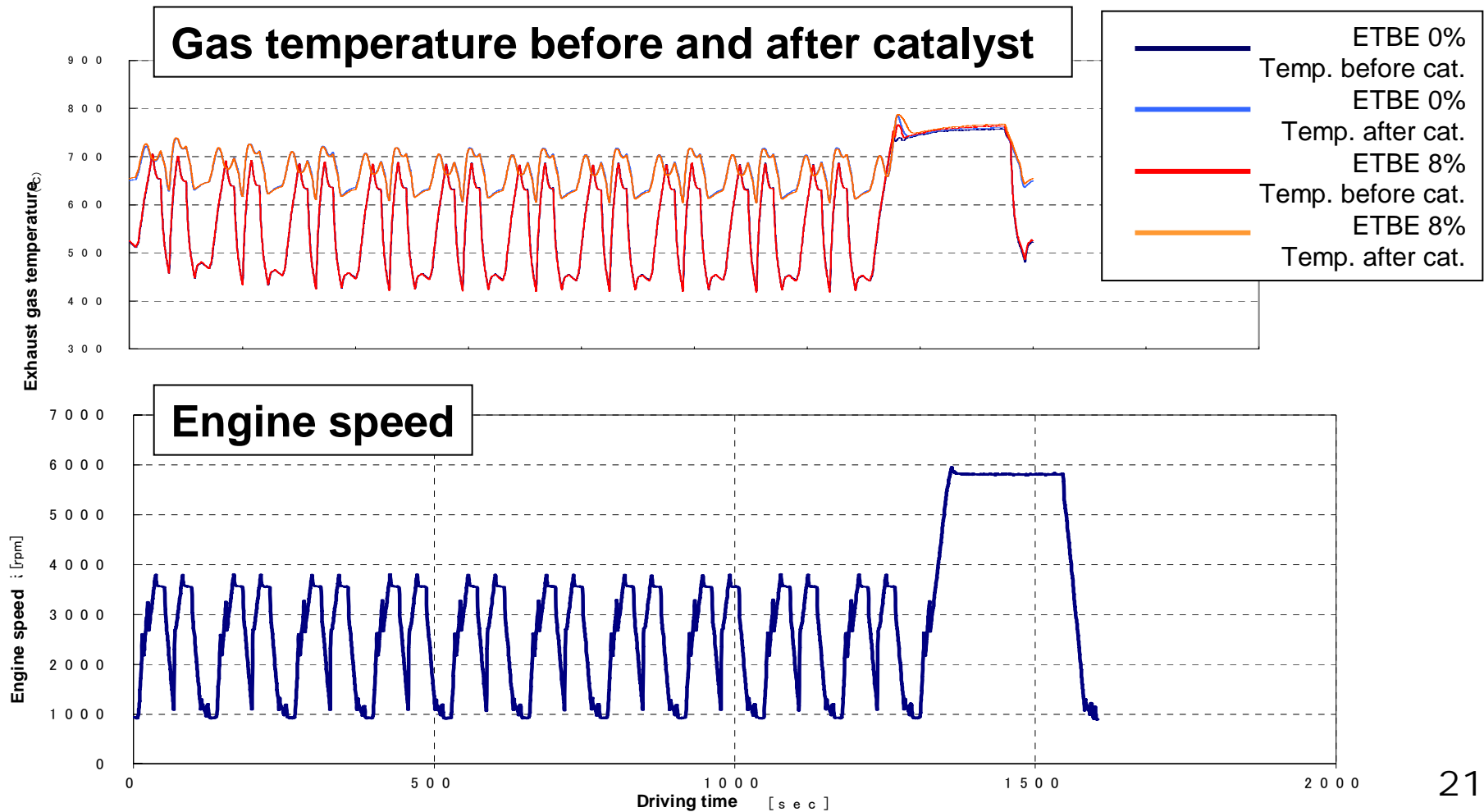
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Catalyst Heat Load

**No increase was observed in catalyst heat load
due to ETBE 8% blend**



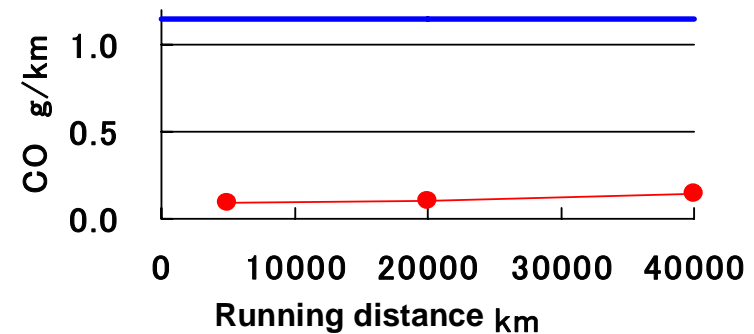


Running Distance and Exhaust Emission Level

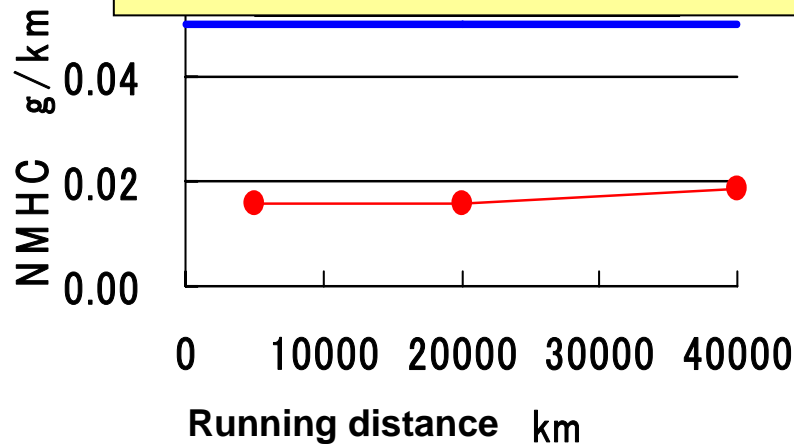
No significant increase in exhaust emissions was observed in durability driving test of ETBE 8% blended fuel

Test vehicle: MPI mini-vehicle/J2GVG
Test fuel: ETBE 8% gasoline
Mode: 11mode \times 0.12 + 10·15mode \times 0.88

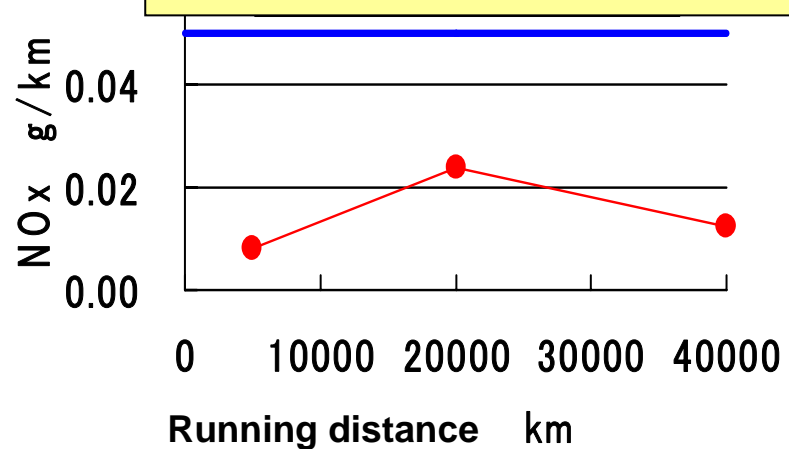
CO 2005 Exhaust Emission Standards



NMHC 2005 Exhaust Emission Standards



NOx 2005 Exhaust Emission Standards



Theme 4-1

Evaluation of Effect of ETBE Blended Fuel

Summary

<p>◆ Outcome</p>	<p>Exhaust emissions and fuel economy tests</p> <p>① No increase was observed in exhaust emissions of 3 regulated substances for ETBE blending, but there was deterioration in fuel economy caused by calorific value reduction due to blending of ETBE.</p> <p>② Concentration of ETBE had small impact on aldehyde emissions of passenger cars and mini-vehicles in 10.15 mode. In 11 mode, increasing trend of acetaldehyde emissions was observed while formaldehyde and acraldehyde emissions showed no such trends.</p> <p>③ Acetaldehyde from motorcycles showed a similar trend to that of passenger cars.</p>
	<p>Durability test</p> <p>No exhaust gas temperature which indicate catalyst heat load rise in ETBE8%, and no significant increase in exhaust emissions after 40000km driving test was observed.</p>



Theme 4-1

Evaluation of Influence of ETBE Blended Fuel

Summary

◆ Outcome	Evaporative emission test No increase in amount of emissions due to increase in blended ETBE quantity for both HSL* and DBL**
	Cold startability test No difference in engine starting time between 0% and 8% ETBE blended fuels in a temperature range from -10 to +10°C
	Material test Regarding metal, rubber and plastic materials, no change in physical properties which might cause a problem was observed with ETBE blended gasoline.

* Hot Soak Loss

** Diurnal Breathing Loss



Theme 4-2

ETBE 8% Blend Fuel, etc. – Fuel Matrix Test

Overview

<p>◆ Study theme</p>	<p>Study effect of oxygenates* on exhaust emissions by conducting fuel matrix test</p>				
<p>◆ Expected outcome</p>	<p>Evaluate exhaust emission quantitatively by using model fuel (with specifications close to market fuels), to obtain knowledge for fuel design guidelines in view of characteristics of ETBE blended fuel**</p> <p>* Focus on ETBE 8% fuel as a featured oxygenate.</p> <p>** Fuel design guidelines are to be determined totally including other criteria other than manufacturing technology and exhaust emissions</p>				
<p>◆ Contents</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 20%; padding: 5px;">Test</th> <th style="padding: 5px;">Fuel / Vehicle</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px; vertical-align: top;"> <p>Fuel matrix test</p> </td> <td style="padding: 5px;"> <p>Fuel:</p> <ul style="list-style-type: none"> • Market average and maximum market level of T50, T90 and aromatics ETBE 8% and 0% for each of the above 4 types (Total of 8 types of fuel) • E3 and ETBE16% for reference <p>Vehicle: 1 MPI and 1 stoichiometric SIDI (emissions level reduced by 50% from 2005 regulations)</p> </td> </tr> </tbody> </table>	Test	Fuel / Vehicle	<p>Fuel matrix test</p>	<p>Fuel:</p> <ul style="list-style-type: none"> • Market average and maximum market level of T50, T90 and aromatics ETBE 8% and 0% for each of the above 4 types (Total of 8 types of fuel) • E3 and ETBE16% for reference <p>Vehicle: 1 MPI and 1 stoichiometric SIDI (emissions level reduced by 50% from 2005 regulations)</p>
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Test Fuel Properties

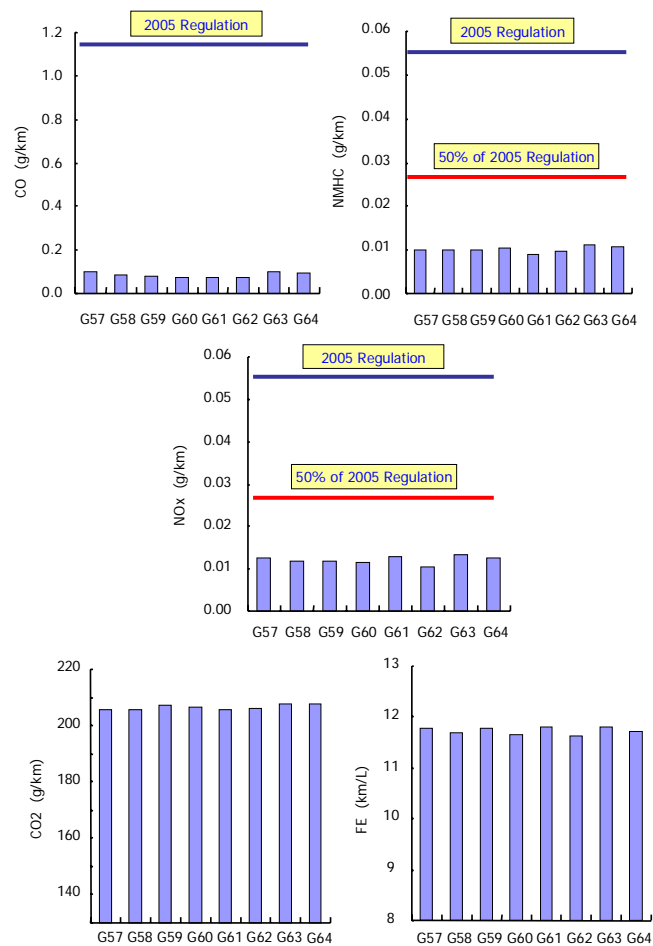
Fuel	Featured property	T50 °C	T90 °C	Aromatic content vol%	Net calorific value MJ/m3	ETBE quantity vol%
G57	Base	95.5	144.0	40.2	32020	0
G58	ETBE8%	92.0	148.5	38.4	31870	8.0
G59	HT50	102.0	149.0	40.6	32170	0
G60	HT50+ ETBE8%	101.0	149.0	40.3	32000	7.9
G61	HT90	93.0	170.0	40.6	32080	0
G62	HT90+ ETBE8%	92.0	166.5	40.3	31900	7.9
G63	HArom	93.0	146.5	46.2	32170	0
G64	HArom+ ETBE8%	96.0	149.0	44.7	32100	7.8

* Octane number of test fuels has been adjusted similarly.

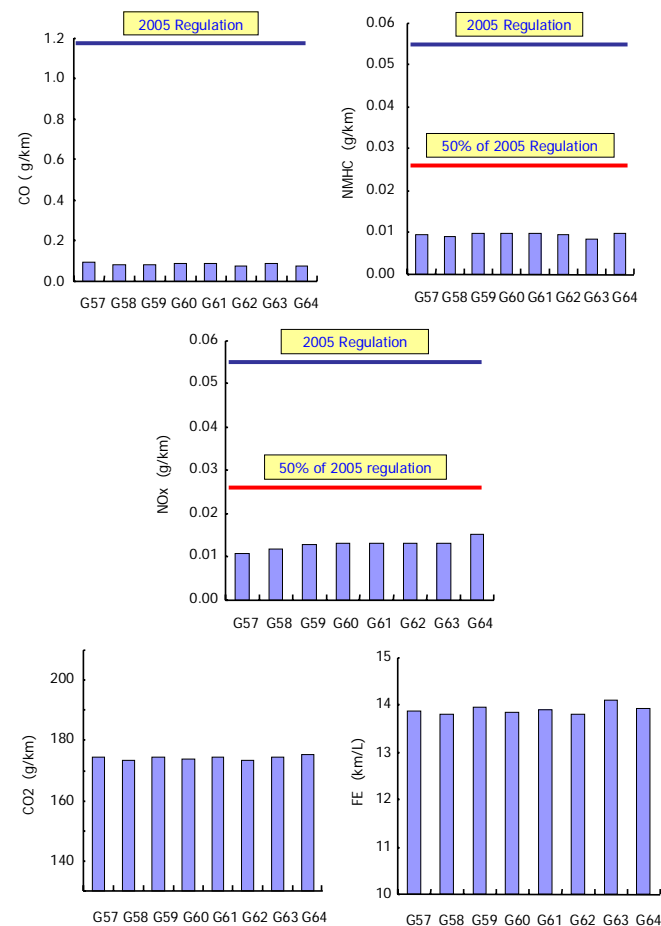


Exhaust Emission and Fuel Economy for High T50, High T90 and High aromatics fuels with/without ETBE Blend

MPI gasoline vehicle / J2GVI vehicle



Stoichiometric SIDI vehicle / J2GVK vehicle



Using model fuels designed assuming use in market. (Both vehicles meet the exhaust emissions level reduced by 50% from 2005 regulations)



Influence of Fuel Properties on Exhaust Emissions and Fuel Economy

- > For ETBE 8% blended fuel, no increase in exhaust emission was observed regarding high-T50, high-T90 and high aromatics.
- > Knowledge for current fuel specifications is applicable to ETBE blended fuels.

Detailed analysis results

① Compared using base fuel (without ETBE) as a reference

Base Fuel: G57		Parameter			
Emission	Vehicle	Base +ETBE 8%	H T50 +ETBE 8%	H T90 +ETBE 8%	H Arom +ETBE 8%
CO	MPI	↓	↓	↓	
	Stoich. DI				
NMHC	MPI				
	Stoich. DI				
NOx	MPI			↓	
	Stoich. DI				
CO2	MPI				
	Stoich. DI				
FE	MPI				
	Stoich. DI				

② Compared using each parameter (without ETBE) as reference

Base Fuel:		Parameter			
Emission	Vehicle	Base +ETBE 8%	H T50 +ETBE 8%	H T90 +ETBE 8%	H Arom +ETBE 8%
CO	MPI	↓			
	Stoich. DI				
NMHC	MPI				
	Stoich. DI				
NOx	MPI			↓	
	Stoich. DI				
CO2	MPI				
	Stoich. DI				
FE	MPI			↓	
	Stoich. DI				

- No significant difference in fuel economy deterioration due to blending of ETBE
 - Considered to result from a small difference in calorific value among test fuels.
- Exhaust emissions tend to decrease slightly.
 - Characteristics varied by vehicle as were shown in the research of EPEFE (1996) and Concawe(2004).



Theme 4-2

Evaluation of Influence of ETBE Blended Fuel

Summary

<p>◆ Outcome</p>	<p>Exhaust emissions test</p> <p>① No increase in exhaust emissions of regulated substances was observed for ETBE blend. No concern was identified when assuming fuels with near commercial quality.</p> <p>② In 11 mode, acetaldehyde showed increasing trend, but there were no such trends for either formaldehyde or acraldehyde. Emission was lower than that in US California regulations. We don't have any special concerns. (A regulated standard exists only for formaldehyde.)</p> <p>(Reference) Study of fuel procurement</p> <p>In this research, we have paid special attention to the fuel design. Study of fuel preparation proved that the fuel property range is broadened by blending and unblending of ETBE and attention will be necessary to match T50 and RON in the market.</p>
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Summary of Research Results

Provided and reflected the following data and the knowledge to technology and policy discussions in the 5-year research activities

- ① Influence of sulfur content on exhaust emissions and fuel economy in driving test
→ We made a quantitative evaluation on the fuel economy improvement of lean-burn SIDI vehicles resulting from sulfur content reduction to 10 ppm. It was proved that fuel economy was improved by 5 to 5.8%.
- ② Influence of T50, T90, and aromatics on exhaust emissions in fuel matrix test
→ Fuels with current control range of T50, T90 and aromatics is compatible with zero emission technology equivalent to J-ULEV level.
- ③ Influence of octane number (RON) on CO₂ emissions and fuel economy is to be determined through engine test and fuel economy simulation for vehicle (MT)
→ Fuel economy improvement by the use of RON95 fuel was 2.80 to 3.35% on the calorie basis (km/MJ).
- ④ Influence of oxygenated fuel (mainly ETBE) on vehicle exhaust emissions and fuel economy/CO₂ and materials
→ There is no problem with the use of ETBE 8% blended fuel for gasoline vehicles in-use .
→ No increase in exhaust emissions was observed in the study using model fuel which has specifications close to market fuels.
→ The emission of aldehyde is lower than the regulated level in North America, and we have no special concern with this.