Influence of Diffusion of Fuel-Efficient Motor Vehicles on Gasoline Demand for Individual User Owned Passenger Cars

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Introduction

Hand in hand with advancing motorization since the 1960s, Japan's motor fuel demand has kept increasing rightward. Above all, gasoline demand grew remarkably along with ever-increasing ownership of private passenger cars. In the 1990s gasoline demand swell a high 3.4%/year on average in reflection to a growing number of passenger cars registered, heavier weight of larger vehicles in new car sales, etc.

On the other hand, newer engine technologies, among others, have rapidly increased motor fuel efficiency in recent years. Including gasoline cars mounted with direct injection engine and hybrid vehicles, fuel-efficient vehicles are now on market after another. In anticipation of the "new fuel efficiency standards from 2010 onward" under the amended "Energy Conservation Act," effective April 1999, the Japanese carmakers are expected to continue R&D on fuel-efficient cars and their market introduction, and fuel-efficient cars are likely to claim an increasing share in new car sales. This paper focuses on how gasoline consumption of private passenger cars can be affected by the emergence of fuel-efficient models (excl. light cars). To this end, questionnaire results are analyzed in an attempt to learn general consumers' preference when buying a car and their concerns over fuel economy. Also, considering what sorts of technologies are introduced in order to improve fuel efficiency of private passenger cars, four cases were assumed to estimate gasoline consumption in the years to 2015.

This time, the estimation covered gasoline consumption of private passenger cars alone. Light cars and freight vehicles, among others, were out of the study scope.

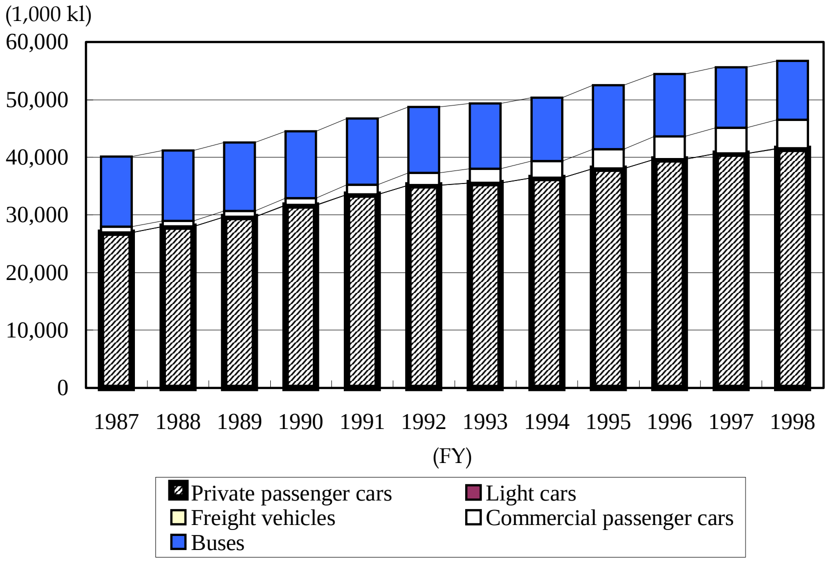
1. Japan's Gasoline Demand and New Fuel Efficiency Standards from 2010 Onward

1-1 Strong gasoline demand to date

Japan's motor gasoline demand has stayed strong to date, and private passenger cars have been responsible for more than 70% of it (Fig. 1-1).

In general, gasoline consumption (demand) depends on the number of gasoline cars registered, and per vehicle mileage and fuel economy (= efficiency of fuel consumption). Of these determinants, the num-

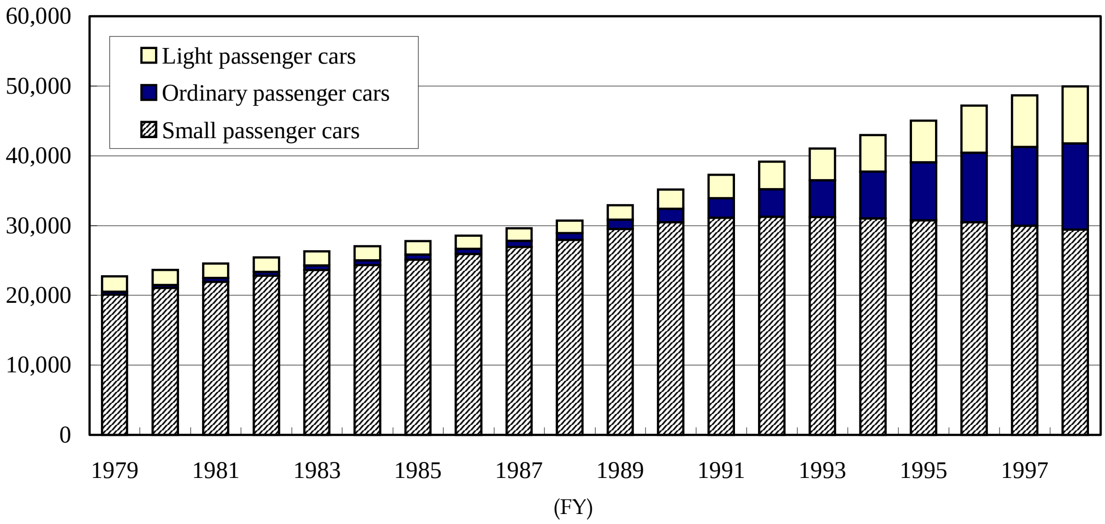
Fig. 1-1 Motor Gasoline Demand in Japan



(Source) The Ministry of Transport (MOT), "Statistical Yearbook of Road Vehicle Transport" ber of gasoline cars registered has been on the constant increase (Fig. 1-2). Though the vehicle makeup can change in terms of displacement and vehicle class, gasoline cars are likely to keep growing in total number for a while. Conversely, per vehicle mileage has shortened in recent years partly because a growing number of families own the plural number of cars each (Fig. 1-3). Because an increasing popularity of passenger cars with bigger displacement since the second half of the 1980s, typically higher-grade sedans and booming recreational vehicles (Fig. 1-4), has offset carmakers' R&D efforts for increasing fuel efficiency, average fuel efficiency of new cars has been improved little (Fig. 1-5). Also, fuel efficiency while actual driving has been deteriorating since 1989 (Fig. 1-5). On top of the aforementioned factors, the deterioration can be attributed to the average driving speed getting slower due to worsening traffic jams, etc. (Fig. 1-6).

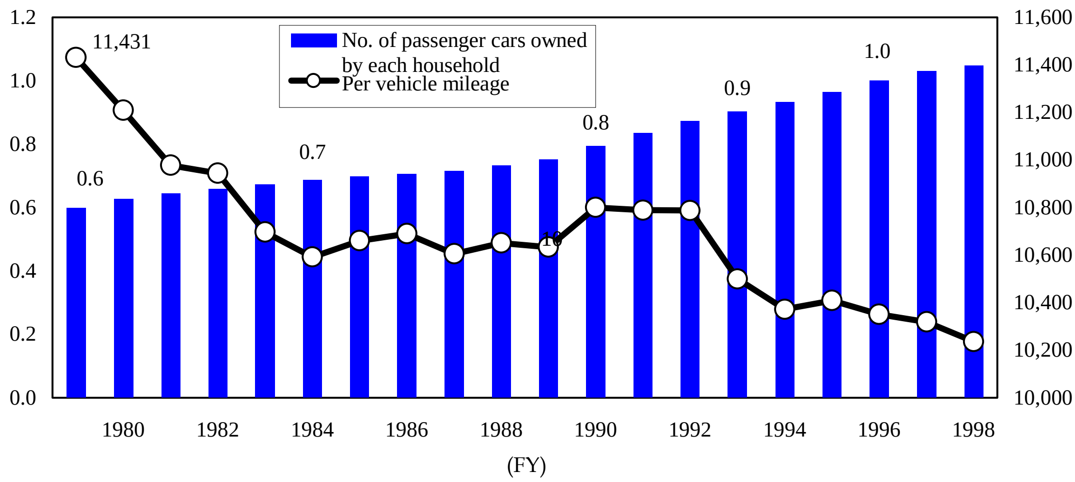
In summary, it appears gasoline consumption has increased overall because positive factors, particularly a growing number of passenger cars and deteriorating fuel efficiency while actual driving, outrun the only negative factor, or shortening mileage per passenger car.

Fig. 1-2 Number of Passenger Cars Registered



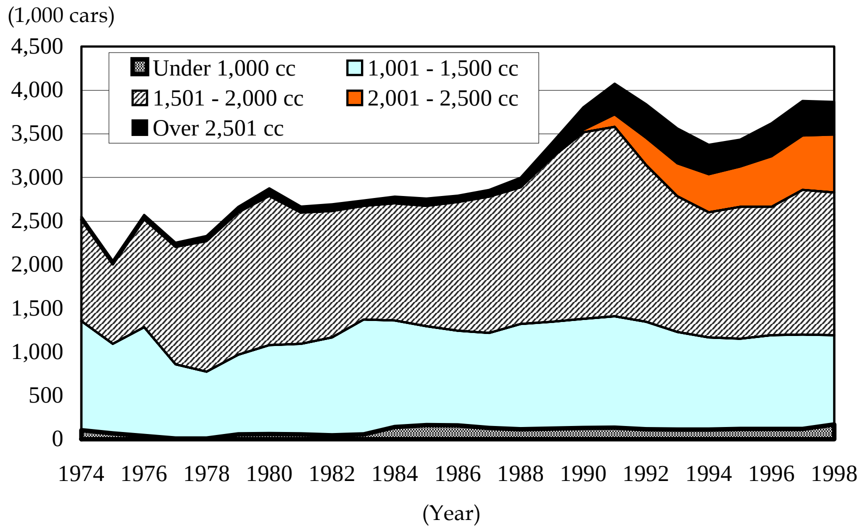
(Source) The Ministry of Transport (MOT), "Statistical Yearbook of Road Vehicle Transport"

Fig. 1-3 Per Vehicle Mileage and Per Household Ownership of Passenger Cars



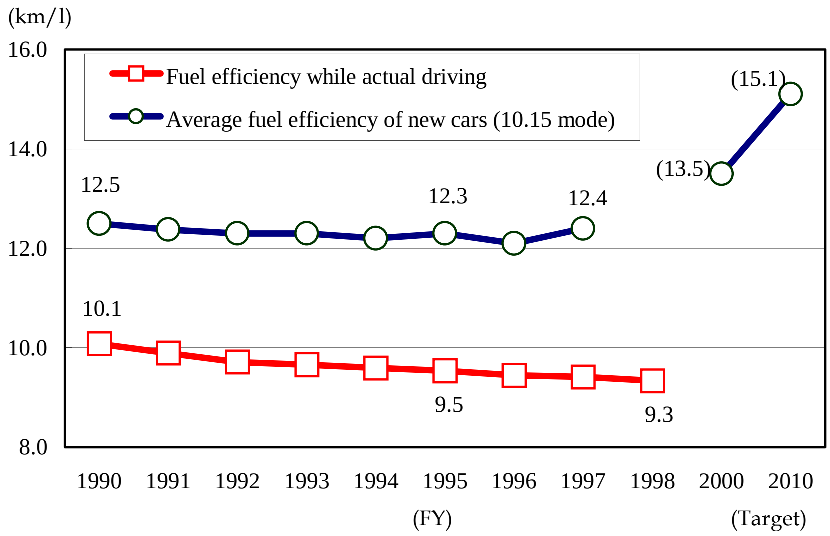
(Notes) 1. Includes diesel- and LPG-fueled vehicles. 2. Not include light cars.
(Source) MOT, "Statistical Yearbook of Road Vehicle Transport," the Association of Car Inspection and Registration, "Changing Numbers of Road Vehicles Registered in Japan"

Fig. 1-4 Gasoline Car Sales Makeup by Displacement



(Source) The Association of Car Inspection and Registration, "Numbers of Registered Road Vehicles"

Fig. 1-5 New Car Average Fuel Efficiency (10.15 mode) and Fuel Efficiency While Driving



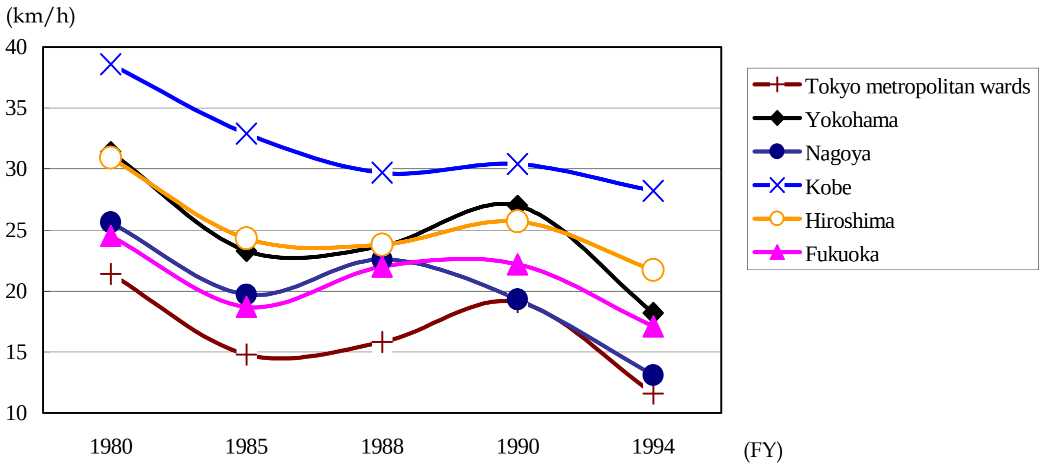
(Source) New-car average fuel efficiencies: Estimated by taking into account the FY 2000 and FY2010 targets, while based on various reference materials, incl. those available from the Fuel Efficiency Standards Subcommittee of the Road Vehicle Committee, a unit of the Council for Transport Technology.

1-2 Global warming and mitigation efforts in the transportation sector

To curb the growth of transport energy consumption has been counted as one of key subjects to combating environmental problems, particularly global warming. The Kyoto Protocol, adopted at the COP3 (third session of the Conference of Parties to the Framework Convention on Climate Change) in 1997, requires Japan's GHG emissions to be cut in 2008 - 2012 by an average 6% from 1990 records. Given the requirement, the Japanese government set specific GHG reduction targets by sector in its "Master Plan for Global Warming Control Measures." As for the increasingly energy-gulping transportation sector, the government set forth that its energy consumption inn 2010, put at 17.30 million kl (crude oil equivalent), should be curbed at 1995 levels (Fig. 1-8).

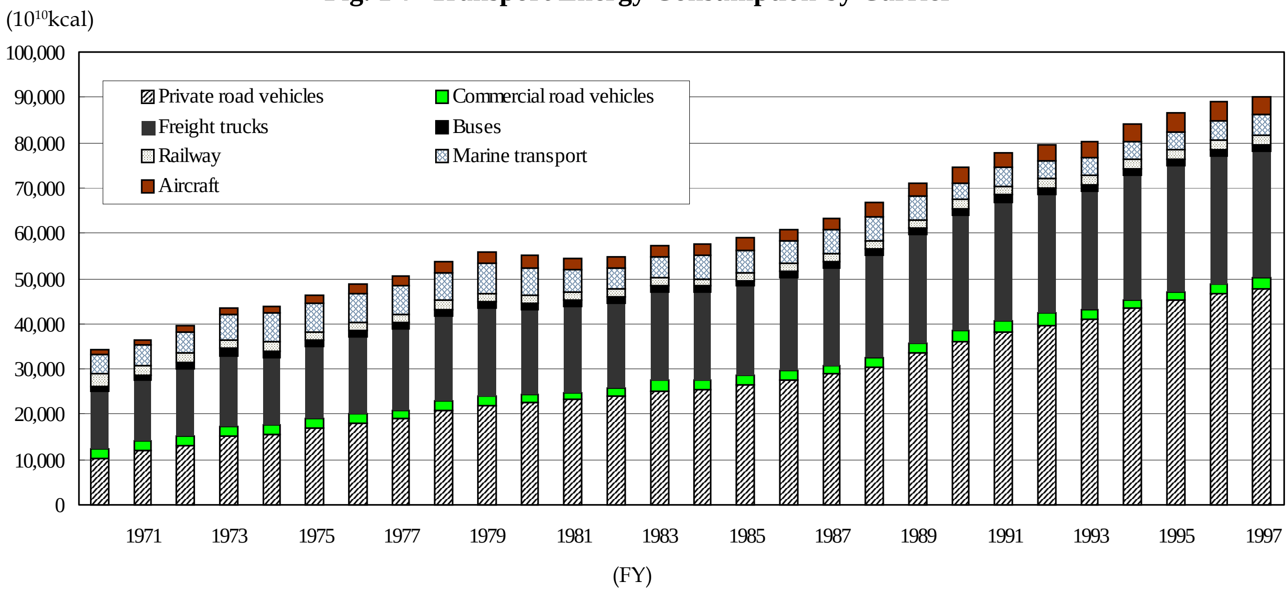
Specific measures to be taken in the transportation sector are roughly divided into eight categories, including "improvement of distribution efficiency" and "traffic control." Of them, the measures categorized in "improvement of motor fuel efficiency" are expected to increase efficiency as much as saving 4.50 million kl equivalent, about one fourths of the sector-wide

Fig. 1-6 Average Driving Speeds While Peak Hours in Major Cities



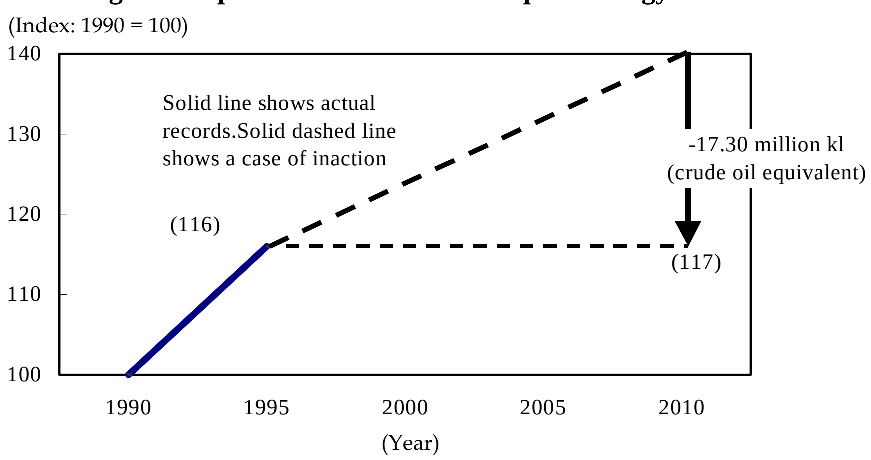
(Source) Nissan Motor, "Automotive Traffic 1998" (original text: Road Traffic Census)

Fig. 1-7 Transport Energy Consumption by Carrier



(Source) EDMC, "Energy & Economy Statistical Handbook"

Fig. 1-8 Japan's Plan to Curb Transport Energy Use



(Source) The Council for Transport Technology, a report on "Tightening of Automotive Fuel Efficiency Standards" (December 1998)

Table 1-1 Transportation Sector's CO_2 Reduction Targets and Specific Measures

Item	Specific measures	Energy saving effect (crude oil equivalent)
Increase motor fuel efficiency.	Increase efficiency of energy use drastically by introducing the top runner approach.	**4.50 million kl**
Promote penetration of clean energy cars.	Subsidies or tax incentives for the purchase of fuel-efficient vehicles.Financial aids like low-interest loans provided by Japan Development Bank, etc.	800,000 kl
Technology development from now on	Promote R&D and dissemination of electric vehicles mounted with efficient lithium cells.	400,000 kl
Improve efficiency of distribution.	Increase efficiency of trucking, while promoting domestic freight transport by ship and rail. Construct viable IT infrastructure for distribution, and reform commercial practice.	3.40 million kl
Traffic control	Smoothen and optimize road traffic flows.To shift passenger transport demand from private passenger cars to public transportation means, like rail and bus.	4.00 million kl
Improve energy efficiency of transport means.	Promote R&D and introduction of less energy-consuming equipment for railway, ships and aviation.	800,000 kl
Promote telecommuting.	Trim traffic volumes involved in traveling on business (incl. commuting) by promoting telecommuting (home offices, satellite offices, TV meetings, etc.) by taking advantage of information & telecommunication technologies.	1.50 million kl
Campaigns to enlighten peoples	Get the public involved in energy conservation efforts through PR activities on environment-conscious driving, etc.	1.90 million kl
Total		17.30 million kl

(Source) MOT homepage (1998 November contents)

Table 1-2 New Fuel Efficiency Standards (10.15 Mode) Effective from 2010 Onward

<Gasoline cars>	1995 actual records	FY2010 targets	Up by
Passenger cars	12.3 km/l	15.1 km/l	22.8%
Freight trucks of under 2.5 tons in vehicle weight	14.4 km/l	16.3 km/l	13.2%
Overall	12.6 km/l	15.3 km/l	21.4%

(Note) Rate of improvement in fuel efficiency from FY1995 records with the ratio to the shipments assumed to remain the same as in FY1995.
(Source) Prepared based on "Automobile Industry Handbook."

conservation target (Table 1-1). Above all, to increase fuel efficiency of gasoline cars is positioned as a theme of crucial importance, with great hopes entertained for its successful outcome.

1-3 New fuel efficiency standards for passenger cars from 2010 onward and needs for fuel-efficient car introduction

The amended "Energy Conservation Act" enforced in April 1999 requires the auto industry to improve, by 2010, average fuel efficiency of gasoline-powered passenger cars (new cars) by 22.8% over FY1995 records in terms of weighted average of the number of cars shipped (Table 1-2). Based on the top runner approach, which takes the most efficient one among currently available products as the standard, the figure of 22.8% was drawn from the assumption that 50% of new cars would satisfy the "top runner standard." In specific terms, GDI (gasoline direct injection) system developed by Mitsubishi Motor Co., Ltd. (hereinafter referred to as "Mitsubishi") was employed as the top runner of gasoline-powered passenger cars.

The enforcement of the amended "Energy Con-

Table 1-3 Tax Incentives for Fuel-Efficient Vehicles

Target: Vehicles already meeting the new fuel efficiency standards
(Gasoline cars: FY2010, Diesel cars: FY2005)

Contents: 300,000 yen deducible from the assessed value for imposing car acquisition tax.
* Private passenger cars --- a 15,000 yen tax cut (300,000 yen X 5%)
* Commercial & light cars --- a 9,000 yen tax cut (300,000 yen X 3%)

Period: Applicable to the vehicles registered or reported from April 1, 1999 onward (2 years).

* Passenger cars

	Class			Standard fuel efficiency
1. Vehicle weight	Under 703 kg			21.2 km/l
2. Vehicle weight	Over 703 kg	-	under 828 kg	18.8 km/l
3. Vehicle weight	Over 828 kg	-	under 1,016 kg	17.9 km/l
4. Vehicle weight	Over 1,016 kg	-	under 1,266 kg	16.0 km/l
5. Vehicle weight	Over 1,266 kg	-	under 1,516 kg	13.0 km/l
6. Vehicle weight	Over 1,516 kg	-	under 1,766 kg	10.5 km/l
7. Vehicle weight	Over 1,766 kg	-	under 2,016 kg	8.9 km/l
8. Vehicle weight	Over 2,016 kg	-	under 2,266 kg	7.8 km/l
9. Vehicle weight	Over 2,266 kg			6.4 km/l

(Source) MOT, "A List of Fuel-Efficient Vehicles Subject to Car Acquisition Tax Credits"

Table 1-4 Conventional Models Entitled to Tax Incentives for Fuel-Efficient Vehicles

Model	Displacement	Vehicle weight	2010 new fuel efficiency standards	Fuel efficiency in 10.15 mode	Transmission
Vitz1000F	997	820	18.8	20.0	Four-speed change AT
Vitz1000U	997	870	17.9	19.6	Four-speed change AT
PLATZ1000F	997	870	17.9	19.6	Four-speed change AT
WAGON R+XV	996	910	17.9	18.6	Four-speed change AT
WAGON R+XV-L	996	920	17.9	18.6	Four-speed change AT
Sunny1500EX Saloon	1,497	1,100	16.0	16.8	Four-speed change AT
Sunny1501EX Super Saloon	1,497	1,110	16.0	16.8	Four-speed change AT
Tino1.8X	1,769	1,400	13.0	13.0	Four-speed change AT
AvancierL-4	2,253	1,620	10.5	10.8	Four-speed change AT

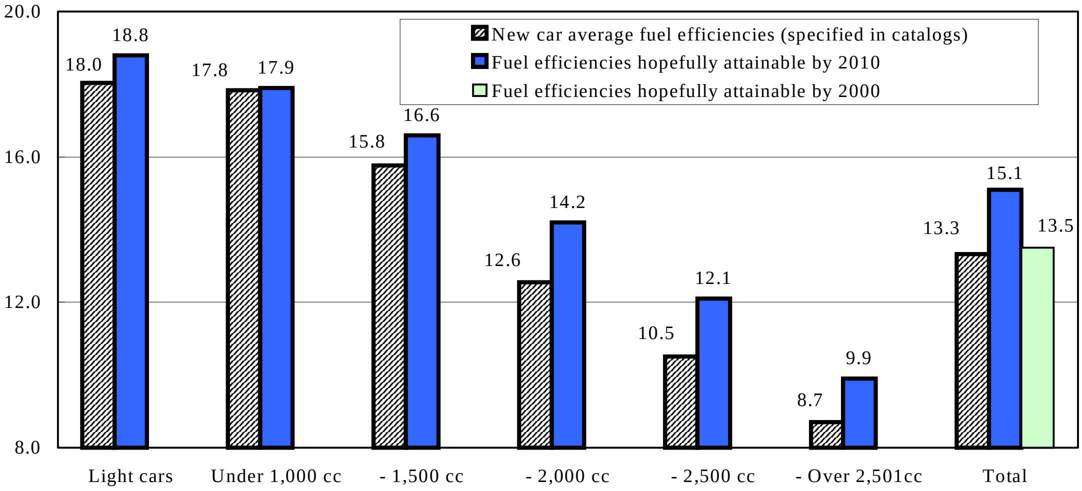
(Note) Not include light cars, manual transmission models, direct injection engine-mounted models, and hybrid vehicles.
(Source) Prepared based on the data on the 524 gasoline-car models appearing in Automobiles Guidebook Vol. 46 (1999-2000).

servation Act" was paired with new tax incentives for fuel-efficient cars, under which those who bought new cars already satisfying the "new fuel efficiency standards from 2010 onward" would be lessened an automobile acquisition tax (Table 1-3). The data contained in the most updated catalogs surveyed unveiled that, among the models (excl. light cars and manual transmission models) not mounted with GDI or any other efficiency-improving engine technology (hereinafter referred to as "conventional cars"), only a few satisfied the new fuel efficiency standards (Table 1-4). Also, at what levels of the scheduled new standards the average fuel efficiencies of conventional cars are staying was analyzed by displacement (Fig. 1-9). It was found the vehicles over 1,500 cc showed greater gaps from the scheduled standards. Perhaps this outcome can be best explained by the presence of top-running GDI-mounted models among the vehicles over 1,500 cc, of which fuel efficiency was taken as the standards for these classes.

Similarly, average fuel efficiencies (10.15 mode) of the passenger cars currently on market, on which data were given in their catalogs, stood at 13.3 km/l as a whole, including light cars. This outcome can be interpreted as that all carmakers have engaged in the new car development and market introduction by

Fig. 1-9 New Car Average Fuel Efficiencies by Displacement vs. 2010 New Standards

(km/l: 10.15 mode)



(Notes) 1. Weighted average so as to reflect the 1995 new car sales makeup by displacement.
2.Not estimated fuel efficiencies by displacement in regard to the 2000 targets.

(Source) Prepared based on the data on the 524 gasoline-car models appearing in Automobiles Guidebook Vol. 46 (1999-2000).

Table 1-5 Major Fuel Efficiency Increasing Technologies for Gasoline Engine

How much fuel efficiency can be increased by improved engines?		
To increase thermal efficiency	4-valve mechanism	0 - 1%
	Variable valve timing	0 - 2%
	Electronically-controlled fuel injector	1 - 2%
	High compression ratio	0 - 1% or less
	Improved combustion chamber	0 - 1%
To reduce losses.	Shift to OHC	0 - 1%
	Reduced frictions	0 - 1%
	Falling number of rotations while idling	0 - 1%
	Employment of motor-driven power steering	2 - 3%

(Source) The Council for Transport Technology, a report on "Tightening of Automotive Fuel Efficiency Standards" (December 1998)

taking efficiency targets of FY2000 (13.5 km/l in 10.15 mode) for granted. Given FY1997 records of 12.4 km/l, the outcome confirms rapidly improving fuel efficiencies of new cars in the last one or two years.

Besides "direct injection system" represented by GDI, "multi-valve system," "variable valve timing" and "electronically-controlled fuel injector" can be cited as major technologies to improve fuel efficiency of gasoline engine. However, all but "direct injection system" are efficiency-increasing technologies of conventional type, and capable of increasing fuel efficiency only by around a few percent each, and by about 10% at best when combined (Table 1-5). The "new fuel efficiency standards from 2010 onward," as stringent as involving a 22.8% increase over FY1995 efficiency records, can hardly be met simply by putting conventional efficiency-increasing technologies to combined use. In other words, to satisfy the new standards, it appears essential to introduce non-conventional technologies, like GDI, or such advanced technologies as "hybridization," that can revolutionarily increase fuel efficiencies.

2. Passenger Cars Getting Fuel-Efficient Ever

2-1 Carmakers' R&D trends on fuel-efficient vehicles

Thanks largely to engine technologies, motor vehicles have become fuel-efficient ever at a high pitch in recent years, and GDI-mounted vehicles and hybrid cars have been introduced into the market one

Table 2-1 Models Mounted with DI and Other Fuel-Efficient Engines

Maker	Engine type	Mounted in	Model	Displacement	Remarks
Mazda	Mirror cycle	1993	Eunos 800	2,254cc	
Honda	Fuel-efficient V-TEC	1995	Civic	1,493cc	VTEC-E + CVT
Mitsubishi	DI	1996	Gallant	1,834cc	
Mitsubishi	DI		Legnum	1,834cc	
Toyota	DI		Corona Premio	1,998cc	
Honda	Fuel-efficient V-TEC	1997	Domani	1,590cc	VTEC-E + CVT
Mitsubishi	DI		Pajero	3,496cc	
Mitsubishi	DI		Diamante	2,972cc	
Mazda	Lean burn		Capella	1,839cc	
Mazda	Fuel-efficient V-TEC		Capella	1,991cc	
Mitsubishi	DI		Challenger	3,496cc	
Honda	Fuel-efficient V-TEC		Accord	1,849cc	
Honda	Fuel-efficient V-TEC		Torneo	1,849cc	
Nissan	DI		Leopard	2,987cc	
Mitsubishi	DI		Chariot Grandis	2,350cc	
Mitsubishi	DI		Charisma	1,834cc	
Mitsubishi	DI		RVR	1,834cc	
Mitsubishi	DI		RVR	2,350cc	
Toyota	Gasoline hybrid		Prius	1,496cc	Nickel hydrogen (Ni-MH) cells 30kW
Mazda	Lean burn	1998	Familia	1,839cc	
Mitsubishi	DI		Pajero Io	1,834cc	
Toyota	DI		Vista	1,998cc	
Toyota	DI		Aldeo	1,998cc	
Toyota	DI		Nadia	1,998cc	
Mitsubishi	DI		Gallant	2,350cc	
Mitsubishi	DI		Aspire	1,834cc	
Nissan	DI		Bluebird	1,769cc	Neo-Di + CVT
Nissan	DI		Primera	1,769cc	Neo-Di + CVT
Nissan	DI		Primera Wagon	1,769cc	
Nissan	DI		Sunny	1,769cc	Neo-Di + CVT
Nissan	DI		Cefiro	2,495cc	
Mitsubishi	DI		Mirage Dingo	1,468cc	
Nissan	DI	1999	Cedric	2,987cc	
Nissan	DI		Gloria	2,987cc	
Toyota	DI		Crown	2,997cc	
Toyota	DI		Athlete	2,997cc	
Toyota	DI		Majesta	2,997cc	
Honda	Gasoline hybrid		Insight	995cc	Ni-MH cells
Mitsubishi	DI		Pistachio	1,100cc	GDI + ASG (stop idling)

(Source) Prepared based on "Automobile Technology Vols. 46 – 53" and "Automobiles Guidebook Vols. 38 – 45," plus the latest information.

Table 2-2 Technology Development to Increase Fuel Efficiency of Power Plant

	DI and other fuel-efficient engines		Hybrid engines		Fuel cells	
Toyota	○	*Some models already mounted with DI engine (D-4). 10.15-mode fuel efficiency up by over 30%. Practical rotational-range torque improved by about 10%.	○	"Purius" on market in 1997. "Estima"slated on market.		*Details of R&D unknown. Methanol reforming process. Hydrogen-containing alloy process under study.
Nissan	○	*Some models already mounted with DI engine (Neo-Di). 10.15-mode fuel efficiency up by over 20%. Medium/low speed rotational-range torque improved by about 5 - 7%.		"Tino HEV" slated on market in 2000.		*Details of R&D unknown.Methanol reforming process. Methanol reforming process employed in the model unveiled at Motor Show.
Honda		*Lean burn engine already on market. *State of DI development unknown.	○	"Insight" on market in 1999. Introduction into all models expressed.		*Details of R&D unknown. Methanol reforming process. Hydrogen-containing alloy process under study. Methanol reforming process employedin the model unveiled at Motor Show.
Mazda		*DI under development (DIREC-G) Maximum power up by about 10%.		NA		*Details of R&D unknown. Methanol reforming process. Hydrogen-containing alloy process under study. Methanol reforming process employed in the model unveiled at Motor Show.
Mitsubishi	○	*DI on market in 1996 (GDI). Currently mounted on 85% of Mitsubishi models. *10.15-mode fuel efficiency up by over 30 - 35%. Medium/low speed rotational-range torque improved by 10%.		"SUW Advance" slated on market in 2000.		*Details of R&D unknown. Methanol reforming process. Hydrogen-containing alloy process under study.Methanol reforming process employed in the model unveiled at Motor Show.
Fuji		*Details of development unknown.		"ELTEN CUSTUM" slated on market in 2001.		*Details of development unknown.

(Note) ○: already on market
(Source) Prepared from various reference materials.

after another. The fuel-efficient vehicles sold as of 1998 numbered an estimated 200,000 cars, accounting for about 6% of the total number of gasoline-powered passenger cars sold, excluding light cars (Table 2-1).

Including direct injection engines and hybrids, the trends of technology development and market introduction among carmakers are summarized based on the information available as of November 1999 (Table 2-2). The information included some of those unveiled at the "Tokyo Motor Show" in the fall of 1999. Fuel cell vehicles are covered as well.

Judging from the fuel-efficient cars that carmakers have already developed and introduced into the market to date, if or not direct injection engines are popularly introduced into the market can be a trump card of making gasoline cars fuel-efficient by around 2010 (with 2 - 3 times of full model changes). Hybrid cars are unlikely to hold the top seat among fuel-efficient cars in the near future, because the carmakers are able to add only one or two models yearly industry-wide for the present. Rapid penetration of fuel cell vehicles in the first half of the 2000s is least likely either, not only because they need further technology improvements and cost reductions, but also because they involve such problems as construction of fuel-supply infrastructure.

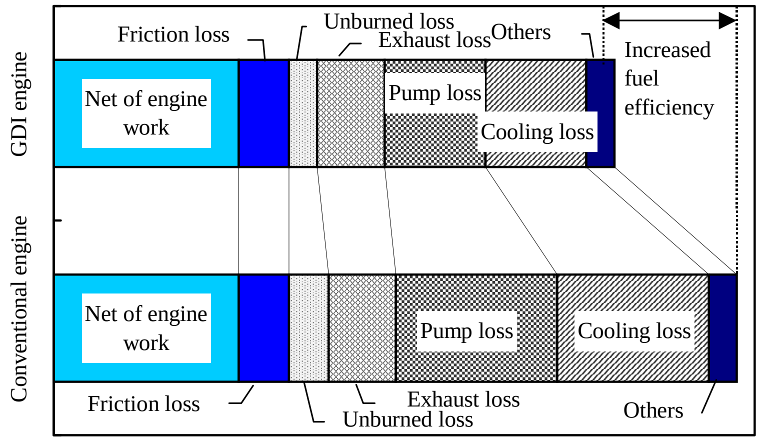
2-2 Trends of major efficiency-increasing technologies

2-2-1 Gasoline direct injection engines

Generally gasoline engines tend to be poor in fuel efficiency, because they consume extra energy in throttling the intake while low-speed rotations. With this problem eliminated, direct injection engines are more fuel-efficient than gasoline engines of conventional type (Fig. 2-1).

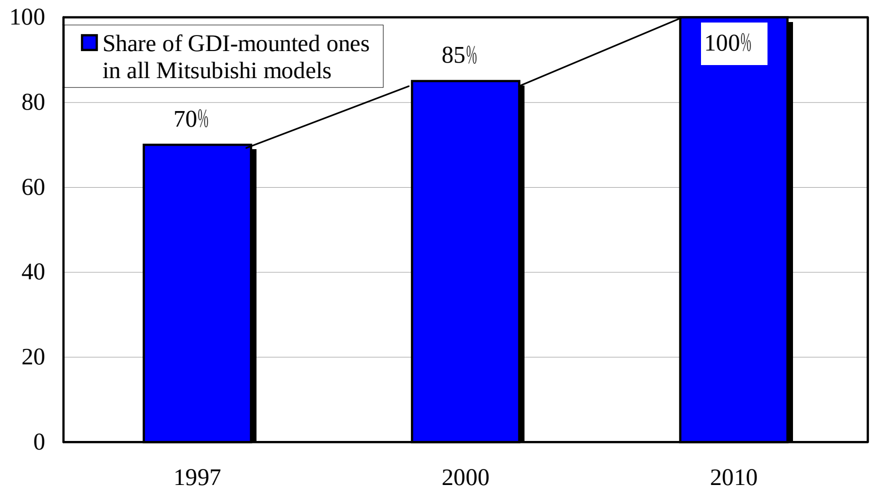
Three years have passed since the first gasoline direct injection engines were mounted in 1996 on

Fig. 2-1 Characteristics of GDI Engine



(Source) Prepared based on the contents of Mitsubishi Motor's homepage.

Fig. 2-2 GDI-Mounted Models from Mitsubishi



(Note) Later, Mitsubishi Motor announced its plan to make all cars mounted with the technology by 2005.
(Source) Mitsubishi Motor's Environmental Report 1999

"Garant," a Mitsubishi model, and on "Corona Premio," a model of Toyota Motor Co., Ltd. (hereinafter referred to as "Toyota"). Later, in reflection to the entry of Nissan Motor Co., Ltd. (hereinafter referred to as "Nissan") and additional models introduced by the pioneering two makers, among other things, GDI-mounted cars have increased at an estimated pace of a few hundred thousands cars annually. Mitsubishi, taking the lead in GDI development, intends to make all new cars GDI-mounted by 2010 (Fig. 2-2).

From the standpoint of easy cost recovery, direct injection engines are said appropriate for large (high-class) vehicles. Yet, they have been mounted largely on the passenger cars of 1,800 - 2,000 classes. Except Mitsubishi, few carmakers have sold GDI-mounted cars of over 2,500 cc classes. GDI engines were introduced into some grades of Crown (Toyota) and Cedric.Gloria (Nissan), given a full model change last year. This introduction is very significant in a point that carmakers began fuel efficiency improvement of their leading models of large size. Judging from Nissan's moves to introduce GDI-mounted cars and Mitsubishi's R&D trends, the strong likelihood is that GDI engines will be introduced into the passenger cars of all displacement classes.

2-2-2 Continuous variable transmission (CVT)

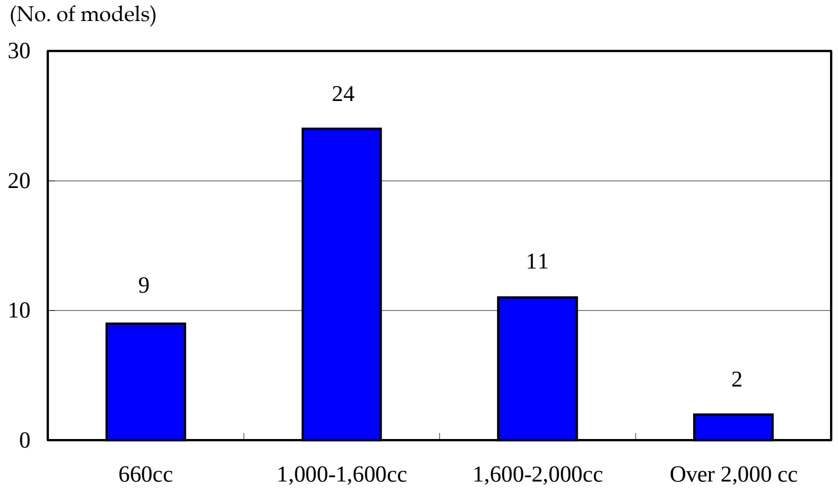
Beside engine improvements, CTV to replace conventional automatic transmission (AT) is expected to be a technology that can contribute considerably to increasing fuel efficiency of automobiles.

CVT stands for continuous variable transmission. Involving no gear changes in varying a speed, CVT allows a free choice of the speed change ratio to engine power. Accordingly, compared with conventional AT with a limited number of speed changes, CVT can transmit engine power more efficiently and thus contribute to increasing fuel efficiency. CVT of conventional type, unable to transmit big power due to its mechanical characteristics, has been employed only in the vehicles of smaller displacement (Fig. 2-3). In recent years, however, improved versions of CVT applicable to the 1,800cc-class vehicles have been developed. Put to a combined use with GDI engine, improved CVT has increased fuel efficiency of the 1,800cc-class gasoline engines more than ever (up from 13.2 km/l to 17.6 km/l in 10.15-mode in Nissan Bluebird case)(Fig. 2-4). Also, Nissan employed CVT of completely new transmission type in Cedric. Gloria, thus proving CVT could be introduced into the models of all classes regardless of varying displacement (or torque).

2-2-3 Hybrid cars

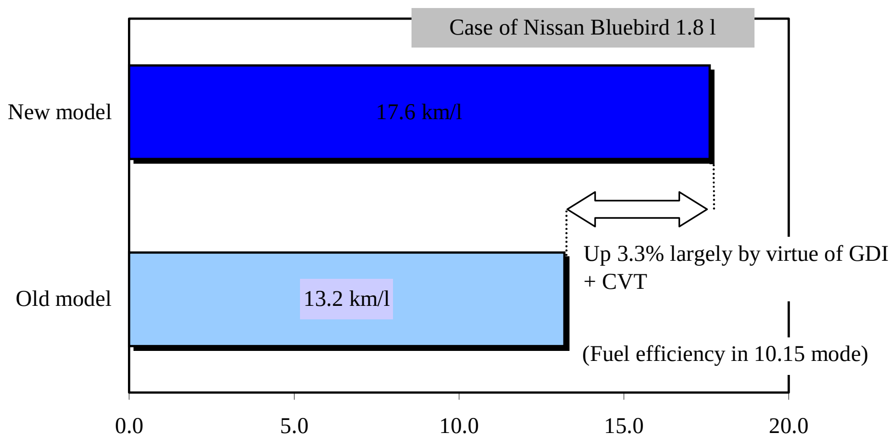
Commercial models of hybrid cars on the market include Purius (Toyota, 1,500cc class) and Insight (Honda, 1,000cc class), and an additional model, which is based on Tino (1,800cc class), is expected to make a debut from Nissan within the year 2000. Next to Purius, Toyota initiated a project to develop a hybrid car based on Estima (2,500cc class). Upon its completion, They will have hybrid cars of almost all displacement classes (Table 2-3). Mitsubishi on its part showed, at the "Tokyo Motor Show" in the fall of 1999, a new concept of hybrid car (1,500cc class model named SUW Advance) in which a GDI engine was combined with an electric motor. This

Fig. 2-3 CVT Introduction by Displacement



(Source) Prepared based on the data on the 524 gasoline-car models appearing in Automobiles Guidebook Vol. 46 (1999-2000).

Fig. 2-4 Effect of Fuel Efficiency Improvement by GDI + CVT



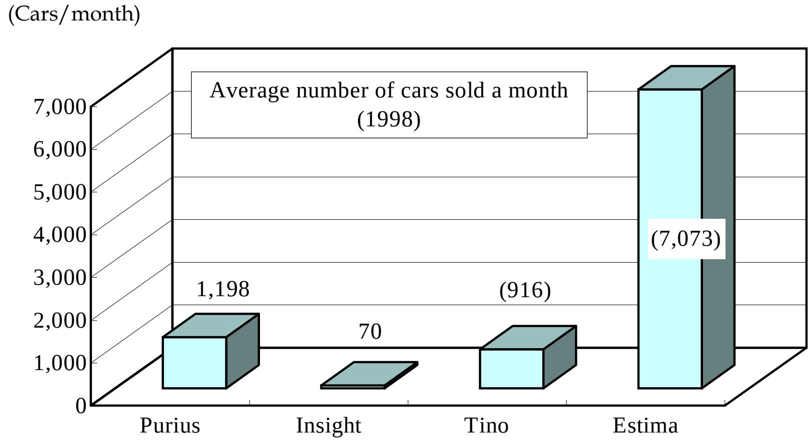
(Source) Prepared based on the contents of Nissan Motor's homepage and "Automobiles Guidebook Vol. 44 (1997-1998)."

Table 2-3 List of Gasoline Hybrid Car Models

Model	Displacement	Fuel cell capacity	10.15-mode fuel efficiency	Vehicle price	Remarks
Prius	1,496cc	Nickel-hydrogen cell 58 kW	28km/l	2.15 mil. yen	
Insight	1,000cc	Nickel-hydrogen cell	*35km/l	2.10 mil. yen	*MT model
Tino HEV	1,500cc	Lithium ion cell Power unknown	NA	NA	Pilot car: DI + CVT
SUW Advance	1,800cc	Lithium ion cell 12 kW	31.5km/l	NA	Pilot car: DI + CVT
HV-M4 (Estima)	2,362cc	Nickel-hydrogen cell Power unknown	39km/l	NA	Pilot car: 4WD, CVT

(Source) Electric Vehicle House's homepage

Fig. 2-5 Sales Records of Hybrid Cars (incl. Models Slated for Hybridization)



(Note) 1. The figures in parenthesis are the sales records of existing models.
2. The number of Insight was estimated from a prompt report.

(Source) Prepared from the Federation of Japan Automobile Dealers Associations, "Numbers of New Car Registered Yearbook 1999," etc.

model employs CVT as its transmission. Once on the market, SUW Advance can be the first 3L cars (capable of driving 100km with three-liter fuels) of the 1,500cc class.

Not to mention their price cuts, to expand the variety of models can be cited a subject of hybrid cars. The sales amount of Purius remains at around 15,000 cars/year (Fig. 2-5). Yet, if a growing number of hybrid cars are sold along with a wider variety of models available, they can produce not a little impact on gasoline consumption.

2-2-4 Fuel cell vehicles

Fuel cell vehicle, designed to run on a motor driven by electricity self-generated by causing hydrogen, the fuel, to react to oxygen, is an automobile of completely new mechanism of dynamics. Its only product is water. Thus, being least environmental load-laden, fuel cell vehicles are expected greatly as the next-generation cars that can replace internal combustion engine cars.

Some carmakers announced their plans to start mass production of fuel cell vehicles by the early 2000s (Table 2-4). Yet, fuel cell vehicles have many subjects to be solved (Table 2-5). Some of them are technical, and include as how to increase current density while electricity generation and how to improve performances of the reformer to take hydrogen out of the fuel. Among others, there are the problems of the manufacturing cost of fuel cells and the installation of fuel-supply infrastructure. On these accounts, rapid penetration of fuel cell vehicles can hardly be expected in the first half of the 2000s. And yet, given such unprecedented moves as the world's leading carmakers oriented toward joint R&D efforts, the possibility

Table 2-4 Fuel Cell Vehicles under Development by Carmakers

Carmaker	Model	Fuel	Planned on market	Fuel cell supplier
Daimler Chrysler	Necar I (1994)	Compressed hydrogen	Mass production slated for 2004 (40,000 cars)	Ballade
	Necar II (1996)	Compressed hydrogen		
	Necar III (1997)	Methanol reforming		
	Necar IV (1999)	Liquid hydrogen		
	Methanol Necar (1999)	Direct methanol		
GM	Pilot model (1998)	Methanol reforming	2004	Ballade/Toyota
	PRESEPT(2000)	Hydrogen-containing alloys		
Ford	P2000(1997)	Compressed hydrogen	2004	Ballade
	FC5(1999)	Direct methanol		
Toyota	RA V4LV(1996)	Hydrogen-containing alloys	2003	Originally developed
	FCEV(1997)	Methanol reforming		
Nissan	Pilot model (1997)	Methanol reforming	2003 - 2005	Ballade
	FCV(1999)	Methanol reforming		
Honda	FCX-V1(1999)	Pure hydrogen	2003 (300 cars)	Originally developed
	FCX-V2(1999)	Methanol reforming		
Mitsubishi	MFCV(1999)	Methanol reforming	2003	Jointly developed with MHI
Mazda	Pilot model (1993)	Hydrogen-containing alloys	NA	Ballade
	Demio FCEV (1997)	Hydrogen-containing alloys		
	Demio FCEV (1999)	Hydrogen-containing alloys		

(Source) Prepared from various reference materials.

Table 2-5 Subjects to Be Solved for Fuel Cell Vehicle Penetration

Subject	Contents	Conditions for penetration
Manufacturing cost	Manufacturing of pilot car costs 20 million yen/50 kW (fuel-cell main body alone)	To be reduced below 250,000 - 300,000 yen/50 kW
Fuels in use	With methanol reforming, fuel-supply infrastructure to be built.	A methanol filling station for every 2,000 cars must be built in general living areas.
	With gasoline reforming, reforming technology to be established and reforming efficiency to be increased.	The subjects specified left must be solved in technical terms.
	With natural gas reforming, pressurized storage type can afford only short-distance driving. Also, reforming efficiency must be increased.	The subjects specified left must be solved in technical terms.
	With pure hydrogen, storage method and supply infrastructure to be established. Also, hydrogen needs to be produced from natural gas, etc.	Fuel-supply infrastructure needs to be built as in methanol case.
Catalysts	Electrode catalysts (platinum, ruthenium) are in use as much as a few tens g/50 kW.	Given platinum output, the catalyst use must be lowered by a digit.
Energy density	Current density taken out of solid macromolecules determines size of whole system and cost.	Current density must be increased a few times at least, and by a digit hopefully, over present records.
Reformer cold start	When taking hydrogen out of hydrocarbon fuels, to get reformer running under high temperatures is time-consuming.	To be shortened from about 3 min. at present to a few tens seconds or less.
Catalysts of reformer	Ruthenium, currently used as a catalyst in methanol reforming, is scarcely produced.	Reformers without using ruthenium must be developed.

(Source) Prepared from various reference materials.

cannot be ruled out that several technical subjects could be eliminated at a stroke.

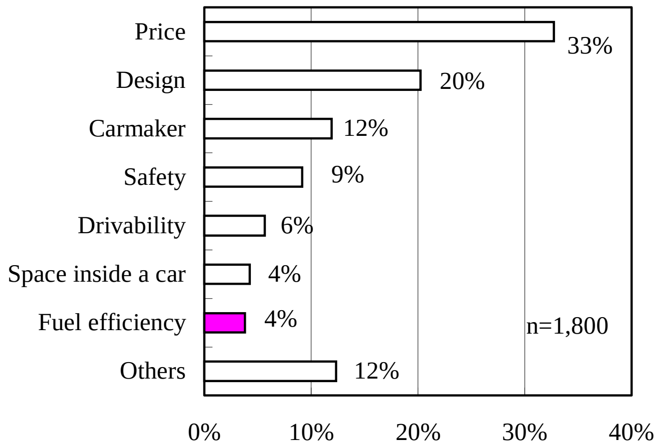
3. Consumers' Concern and Preference of Fuel-Efficient Cars

Covering general consumers nationwide, a questionnaire survey was conducted to learn and analyze their concerns over fuel-efficient cars. In the questionnaire, the "fuel-efficient vehicles" are defined as the "fuel-efficient models" which were designed to be about 20% more fuel-efficient than regular models of the same vehicle class and displacement.

To a question of "what is the primary concern when you buy a car," the most popular answer was the "price" (33%), followed by "design" (20%), "carmaker" (12%), and "safety" (9%) in this order (Fig. 3-1). Those who cited "fuel efficiency" were as minor as 4% of the respondents. Yet, given an additional question of "do you consider a purchase of fuel-efficient model, if available among the vehicle class you plan to buy," 76% of the whole respondents answered "yes," thus unveiling considerable potential needs for "fuel-efficient models" (Fig. 3-2). Those who answered "yes" were also asked why. While a majority (54%) of these respondents reasoned that "a fuel-efficient model is better if the remaining specifications are the same," those who cited "contribution to the global environment" reached 19% of this respondent group (Fig. 3-3). These questionnaire results suggest that, while the consumers' primary concerns when buying a car are the price and their liking (ex. car design, carmaker, displacement), they are also strongly interested in fuel-efficient vehicles for the reason to reduce the fuel cost, or in reflection to growing concerns over environmental problems.

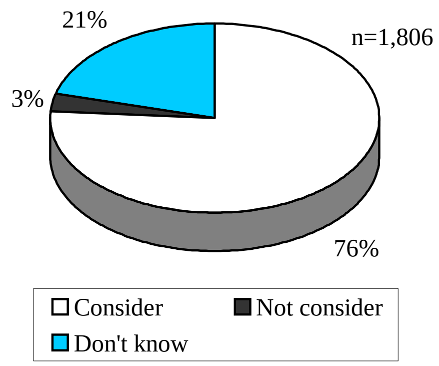
If or not the ownership of fuel-efficient vehicles can increase ultimately depends on the consumers' choice. The respondents who answered "yes" were asked how much extra they were ready to pay for a fuel-efficient model. While the specific amounts they cited varied greatly (from 50,000 yen to over 250,000

Fig. 3-1 Consumers' Primary Concern When Buying A Car



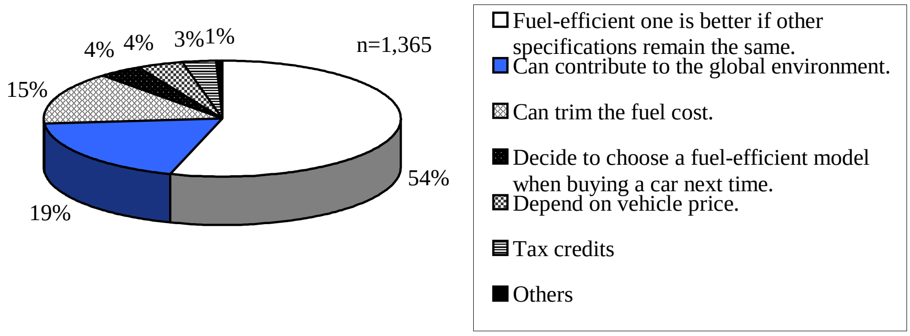
(Source) Prepared based on the automobile questionnaire results

Fig. 3-2 Possibility of Considering Fuel-Efficient Model



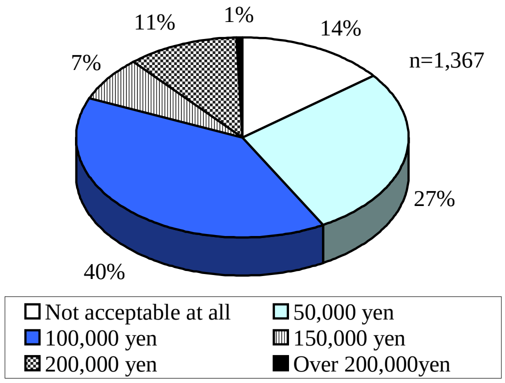
(Source) Prepared based on the automobile questionnaire results

Fig. 3-3 Reasons for Considering Fuel-Efficient Model



(Source) Prepared based on the automobile questionnaire results

Fig. 3-4 How Much Extra Cost Acceptable When Buying Fuel-Efficient Model?



(Source) Prepared based on the automobile questionnaire results

yen), as much as 86% of this respondent group answered "a higher price was acceptable" (Fig. 3-4). Of them, those who answered "a price increase of over 100,000 yen was acceptable" accounted for 58% (44% of the whole samples). According to the catalogs surveyed this time, no price trends were confirmed as a whole, with some GDI-mounted vehicles about 100,000 yen more expensive, but others even cheaper a little, than their previous models without GDI. In summary, this respondent group (44%) thought they could accept a higher cost of "fuel-efficient model," if the price increase remained at around 100,000 yen plus a few tens thousand yen. As a matter of course, a larger number of consumers (76% of the whole respondents, who answered "yes" to the first question) are expected to buy fuel-efficient vehicles if priced equal to, or cheaper than, conventional models.

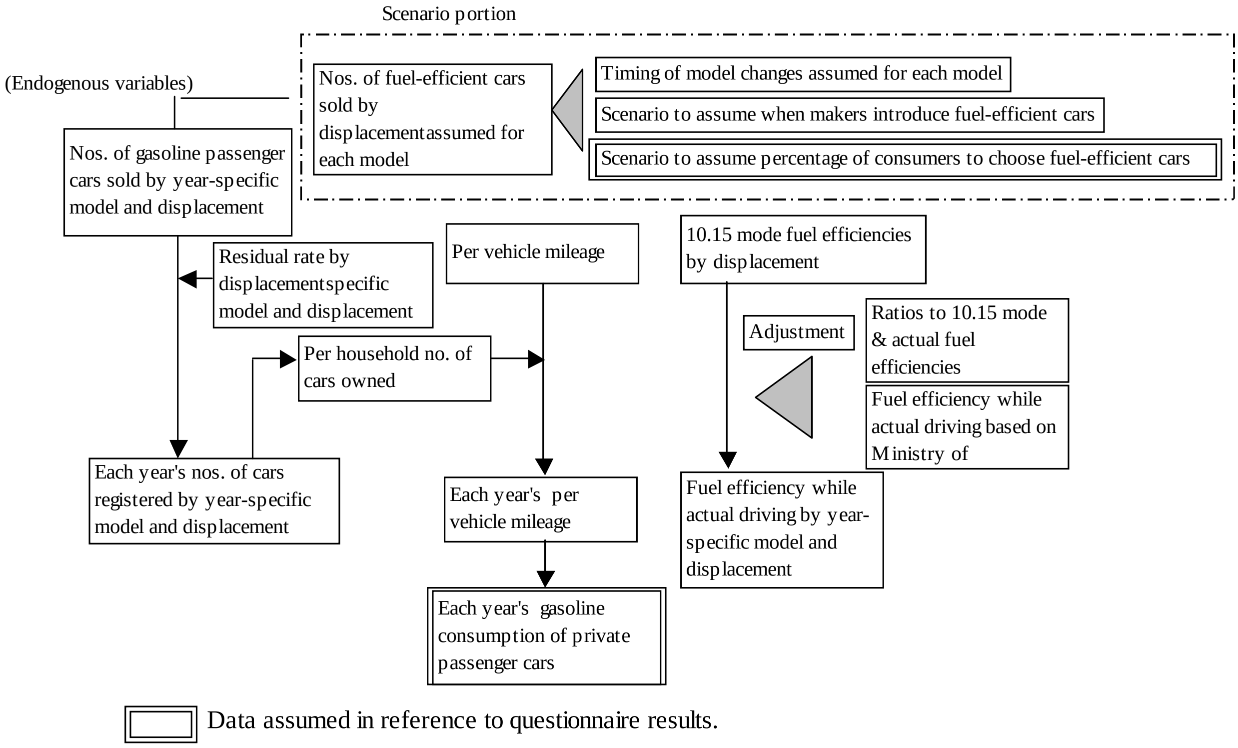
4. Estimation of Gasoline Consumption of Private Passenger Cars

Here, "fuel-efficient vehicles" are defined as the vehicles that meet the 2010 new fuel efficiency standards with some efficiency-increasing technology mounted. While considering such factors as technical characteristics, commercialization trends, and consumers' concerns (degree of preference) of fuel-efficient vehicles, what impacts could be produced on gasoline consumption of private passenger cars (excl. light cars) in the years to 2015 were assessed (Fig. 4-1).

4-1 Case-setting by varying penetration degree of fuel-efficient vehicles

Generally passenger cars are subject to a model change every 4 - 5 years, and their performances, including fuel efficiency, are improved on that occasion. It means the carmakers have the chances of model change twice before the new fuel efficiency standards, effective 2010 onward, become applicable to gasoline-powered passenger cars. Given the model change cycle of specific vehicles, two scenarios of "timing of market introduction of fuel-efficient models" were prepared in making the impact assessment this time (Table 4-1, Fig. 4-2). One is a scenario where the carmakers are assumed to introduce, one after another, new models that satisfy the 2010 new fuel efficiency standards during the first half of the

Fig. 4-1 Flow of Impact Assessment of Fuel-Efficient Cars on Gasoline Consumption



(Source) Prepared by IEEJ.

Table 4-1 Scenarios for Impact Assessment of Fuel-Efficient Cars on Gasoline Consumption of Private Passenger Cars

Scenario	Scenario image	Carmakers . responses	Consumers . choice when buying cars	New policy measures	New fuel efficiency standards	Sales mix image
Case 1	Consumers poorly environment-conscious. Few additional fuel-efficient models. Technology improving trends kept on.	Not to add models meeting fuel efficiency standards. Increase fuel efficiency moderately. Delays in fuel cell vehicle development.	Fuel-efficient cars sold almost as many as now.	Not provided specially.	2010 targets unattainable	Conventional cars: Keep present share. DI & others: Sold as many as now.Hybrids: Level off FC: A little from 2010 onward
Case 2	Growing environment-consciousness. Industry's reluctant commitments. Technology improving trends kept on. Additional policy aids from 2005 and on.	Add fuel-efficient cars on every occasion of model change from 2005 and on. Delays in fuel cell vehicle development.	When buying for replacement,30 - 50% of consumers choose fuel-efficient one, if available among their preferable models.	Extra incentives for fuel-efficient cars from 2005 onward.	Targets attained before 2010.	Conventional cars: Share to fall in 2nd half of the period. DI & others: Share to rise in 2nd half of the period. Hybrids: To increase in 2nd half of the period. FC: Almost the same as hybrids at introductory stage.
Case 3	Growing environment-consciousness. Industry's positive commitments.Technology improving trends kept on. Additional policy aids given earlier.	Add fuel-efficient cars on occasion of model changes from 2000 and on. Accelerated fuel cell vehicle development.	The same as in Case 2.	Extra incentives for fuel-efficient cars from 2000 onward.	Targets attained before 2010.	Conventional cars: Share to fall. DI & others: Share to increase. Hybrids: To increase. FC: Almost the same as hybrids at introductory stage.
Case 4	Rapidly growing environment-consciousness. Industry's positive-ever commitments. Technology improving trends kept on. Additional & positive policy aids given earlier.	Add fuel-efficient cars on occasion of model changes from 2000 and on. Accelerated fuel cell vehicle development.	When buying for replacement,40 - 70% of consumers choose fuel-efficient one, if available among their preferable models	Positive supports to makers and consumers	2010 targets attained to considerable extent	Conventional cars: Share to fall. DI & others: To outnumber Case 3. Hybrids: To outnumber Case 3. FC: Introduced more than expected.

(Note) FC: fuel cell; fuel cell vehicles
(Source) Prepared by IEEJ.

2000s (first chance of model change)(Case 3). The other scenario assumes that the carmakers leave the responses to the new standards to the second half of the 2000s (second chance of model change)(Case 2).

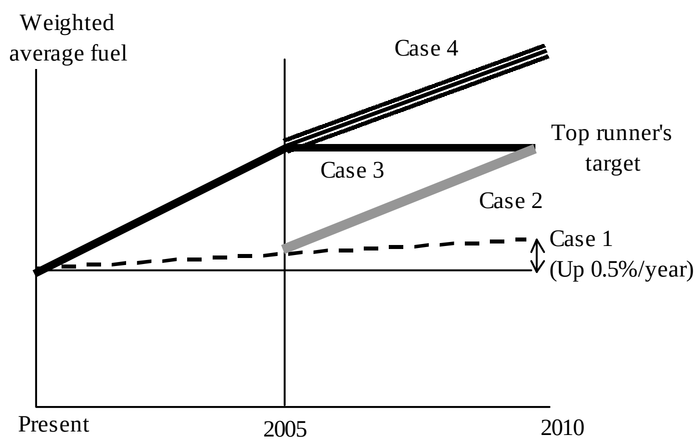
On the degree of consumers' "preference of fuel-efficient vehicles" in buying a car, it was assumed, based on the questionnaire results, that (as high as) "30 - 50%" of consumers would choose fuel-efficient models, if available among specific vehicles they plan to buy.

Also, in order to assess to what extent these cases would be effective in energy conservation, two scenarios were prepared. One is a business-as-usual scenario, where the carmakers' market introduction of fuel-efficient vehicles is assumed to remain unchanged from present conditions, and the consumers' preference of fuel-efficient models unchanged (low) as well (Case 1 where the 2010 new fuel efficiency standards are unattainable). In the other scenario, all assumptions but the degree of consumers' preference are the same as in Case 3 (Case 4). In Case 4, the degree of consumers' preference is assumed to rise to a (very high) level of "40 - 70%." Meanwhile, the 2010 new fuel efficiency standards under the Energy Conservation Act as amended are met before 2010 in Cases 2 - 4.

4-2 Estimated gasoline consumption of private passenger cars

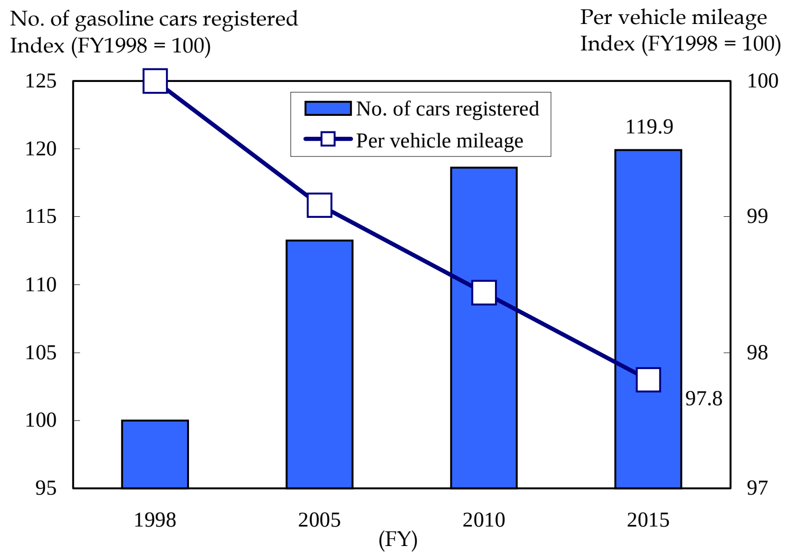
Estimation was made with the following points taken into account. First, on the number of gasoline cars registered (Fig. 4-3), their numbers were estimated for each year by displacement and year-spe-

Fig. 4-2 Image of Increasing Average Fuel Efficiency of New Cars



(Source) Prepared by IEEJ.

Fig. 4-3 No. of Gasoline Cars Registered and Estimated Per Vehicle Mileage

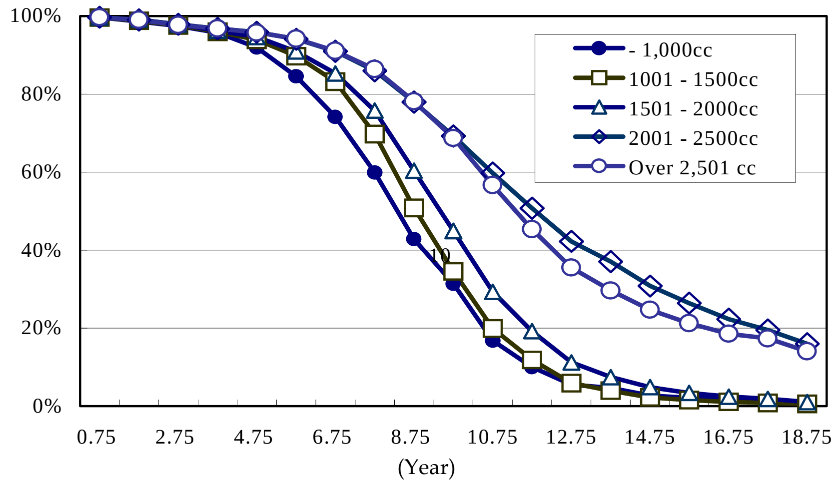


(Source) Prepared by IEEJ.

cific model from the numbers of first-year registration and the residual rates of vehicles by displacement (Fig. 4-4). Second, per vehicle mileage in the future (Fig. 4-3) was estimated by first figuring out present mileage from the questionnaire result (9,605 km/year on average among gasoline-powered passenger cars), then considering an expected growth of per household car ownership. Also, this time, on new cars in the future, their fuel efficiencies while driving were estimated by year-specific model as follows. First, coefficients were drawn from the relations between fuel efficiencies while driving of the cars owned by the respondents, unveiled by the questionnaire, and fuel efficiencies of corresponding models in 10.15 mode specified in their catalogs. Then, the coefficients were multiplied by average fuel efficiency of year-specific new cars in the future (Fig. 4-5).

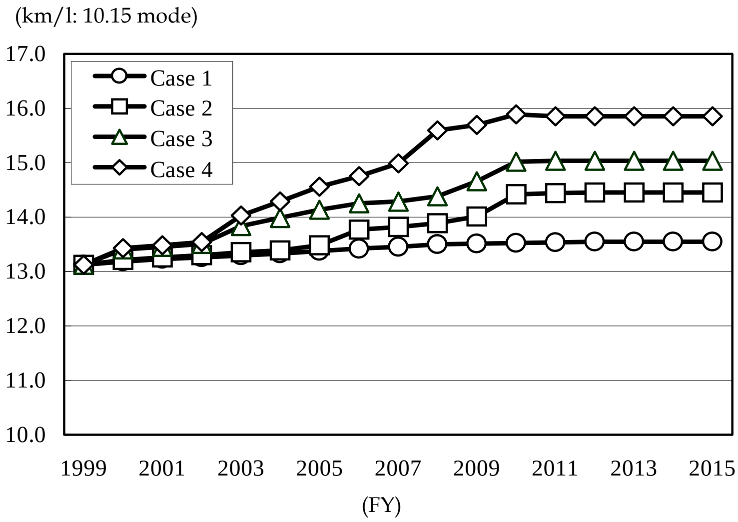
In Case 1, gasoline consumption of all private passenger cars but light ones would amount to 47.10 million kl as of 2015, an increase of about 5.60 million kl over 1998 records, or up 0.7%/year on average (Fig. 4-6). Even if the share of fuel-efficient vehicles in new car sales won't grow in the future, the growth of gasoline consumption would slow down gradually, because the vehicle stock is replaced with newer passenger cars, more fuel-efficient than older models. Under this condition, Case 2, which assumes introduction of fuel-efficient vehicles from 2005 onward and a higher degree of consumers' preference, would involve lesser gasoline consumption, down 5.4% or about 2.60 million kl from Case 1 as of 2015, with an average growth staying at 0.4%/year since 1998. While Case 2 assumes rather moderate introduction of fuel-efficient vehicles, the simulation

Fig. 4-4 Average Residual Rates of Gasoline Cars by Displacement



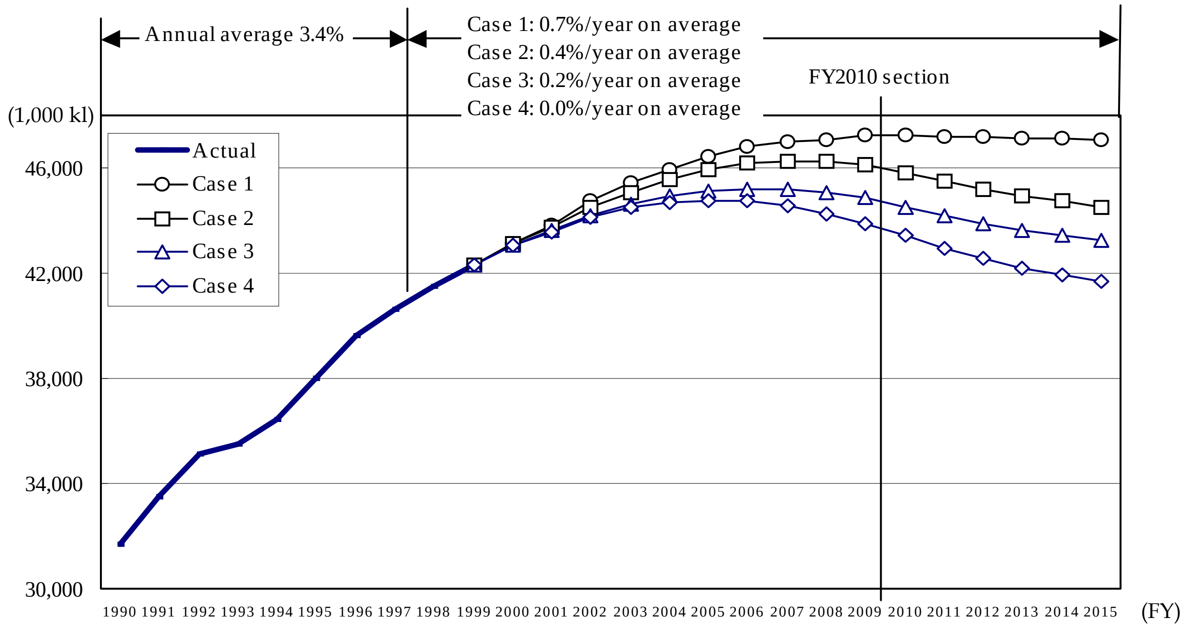
(Source) Prepared from the Association of Car Inspection and Registration, "Numbers of Registered Road Vehicles."

Fig. 4-5 Estimations of New Car Fuel Efficiency by Case



(Source) Prepared by IEEJ.

Fig. 4-6 Estimated Gasoline Consumption of Private Passenger Cars



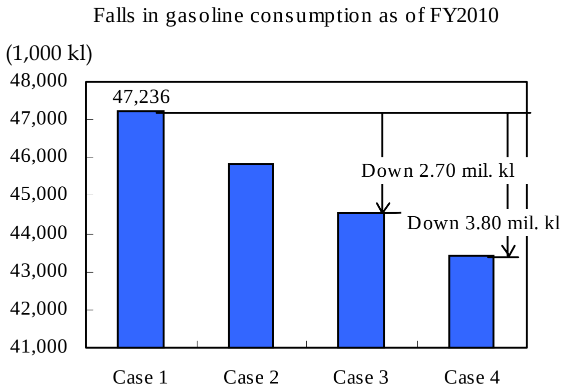
<Gasoline consumption>

(Mil. kl)

	2000	2005	2010	2015
Case 1	43.1	46.4	47.2	47.1
Case 2	43.1	45.9	45.8	44.5
Case 3	43.1	45.1	44.5	43.2
Case 4	43.1	44.8	43.4	41.7

<Annual average growth>

	2015/1998	2005/2000	2010/2005	2015/2010
Case 1	0.7%	1.5%	0.3%	-0.1%
Case 2	0.4%	1.3%	-0.1%	-0.6%
Case 3	0.2%	0.9%	-0.3%	-0.6%
Case 4	0.0%	0.8%	-0.6%	-0.8%



(Source) Prepared by IEEJ.

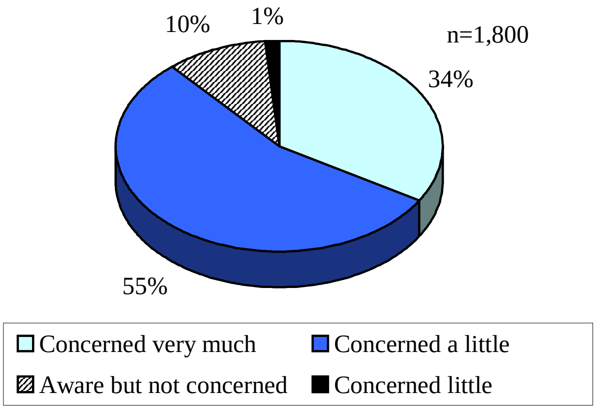
showed that gasoline consumption of private passenger cars reached a peak in 2007.

In Case 3, which assumes immediate market introduction of fuel-efficient vehicles (though the consumers' preference is assumed to remain unchanged from Case 2), gasoline use as of 2015 would be smaller by 8.2%, or about 3.80 million kl less, than in Case 1. Again, the simulation of Case 3 showed that gasoline use would turn downward from 2007 onward, with the growth rate averaging 0.2%/year from 1998. In Case 4, which assumes earlier introduction of fuel-efficient vehicles and even higher degree of the consumers' preference (= a case of accelerated penetration of fuel-efficient vehicles), gasoline consumption in 2015 would be smaller by 11.4%, or about 5.40 million kl less, than in Case 1. The simulation of Case 4 plotted that gasoline consumption would turn downward after a peak in 2005, then return to an almost identical level to 1998 records (41.50 million kl).

5. Summary

The Japanese government showed, in its plan to mitigate global warming by around 2010, an intention that the transportation sector, getting more energy-intensive than ever, should curb its energy consumption in 2010 at 1995 levels. As one of specific measures to help achieve the goal, a target was set for "increasing fuel efficiency of automobiles," including freight vehicles, as much as trimming energy use of 4.50 million kl (crude oil equivalent). These estimation results, covering gasoline-powered private passenger cars alone, may be too limited to discuss

Fig. 5-1 Consumers' Concerns over Global Warming Problems



(Source) Prepared based on the automobile questionnaire results

Fig. 5-2 Consumers' Recognition of Tax Incentives for Fuel-Efficient Cars

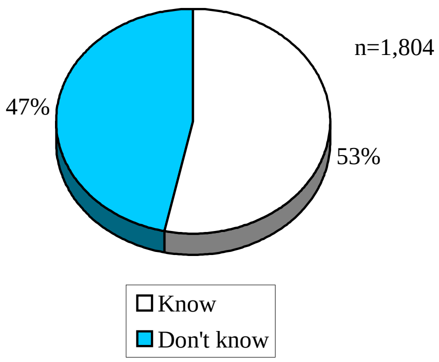
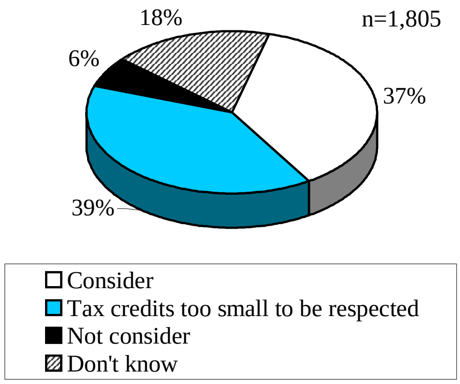


Fig. 5-3 Do Consumers Consider Tax Incentives When Buying A Car?



(Source) Prepared based on the automobile questionnaire results

what impacts increasing fuel efficiencies can produce on automobiles as a whole. Yet, at least the comparison between Cases 1 and 3 showed that Case 3, which assumed earlier introduction of fuel-efficient vehicles and consumers' stronger preference thereof, would involve lesser gasoline consumption by 2.70 million kl than Case 1 as of 2010. Moreover, in Case 4, where consumers were assumed to show a stronger preference of fuel-efficient vehicles, the decline from Case 1 was widened by1.10 million kl to 3.80 million kl. These results suggest that, not to mention earlier market introduction of fuel-efficient vehicles, getting the consumers more conscious of fuel-efficient cars (a stronger preference) can have an extremely massive impact on gasoline consumption of private passenger cars.

The questionnaire conducted this time also contained questions about the consumers' "concerns over global warming problems." When combined, those who answered "concerned very much" (34%) and those who did "concerned a little" (55%) accounted for a high 89% of the whole respondents (Fig. 5-1). Also, among those who answered they would "consider a purchase of fuel-efficient vehicles," about 20% cited "contribution to the global environment" when asked why. On the other hand, however, on the "tax incentives for fuel-efficient vehicles," nearly half (47%) answered "no" to a question "do you know availability of the tax incentives" (Fig. 5-2). Questioned "do you take the tax incentives into consideration when buying a car," those who answered "the tax credits are too small to be respected" (39%) outnumbered those who said "yes" (Fig. 5-3). From these results, a growing number of consumers are expected to change their daily behaviors while paying keener attention to environmental problems. At the same time, we can easily imagine that supporting measures, if effectively taken in policy terms, can direct many peoples toward a "consumer's choice" that can contribute to reducing environmental loads.