STAFF REPORT

TRANSPORTATION TECHNOLOGY STATUS REPORT

I. ALTERNATIVE FUEL VEHICLES

II. AUTOMOTIVE FUEL ECONOMY

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STATE OF CALIFORNIA
ENERGY COMMISSION

CALIFORNIA ENERGY COMMISSION

Pete Wilson, *Governor*

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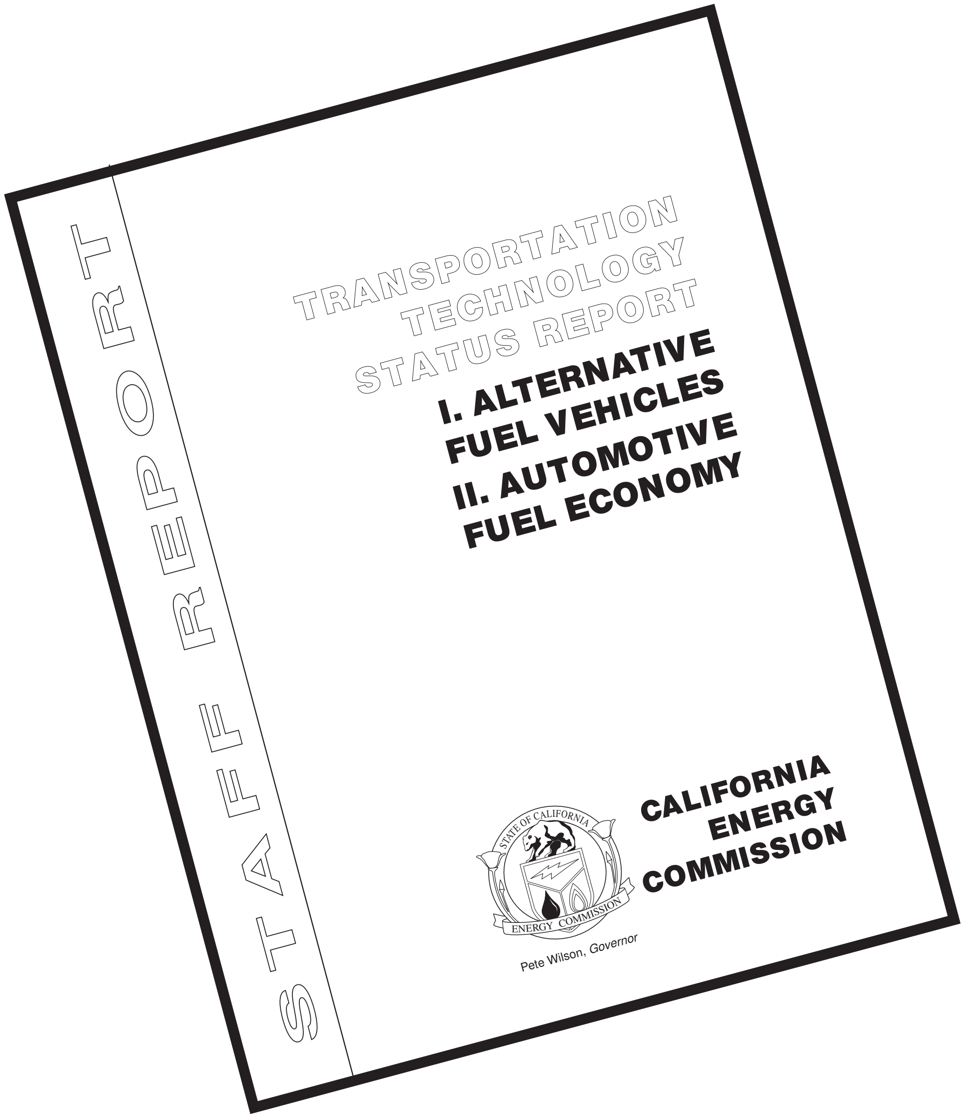

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Transportation Technology Status Report
Introduction

Transportation remains a vital component of California's economy and affects the quality of life for many individuals. The current system, however, also creates challenges and problems. The state can play an important role in identifying options to help maximize the benefits currently enjoyed from transportation, and also reduce its adverse impacts. For example, the transportation sector contributes large amounts of air pollutants in California. Tailpipe and evaporative emissions contribute to the formation of ozone. Tailpipe emissions also add to carbon dioxide emissions from fossil fuel combustion. Through dependence on one fuel the state economy is vulnerable to petroleum price increases which pose an energy security risk. Reducing this risk can be achieved by developing alternative fuel vehicle technologies that offer choices for the driving public.

Expected increases in population and personal vehicle use will lead to higher fuel consumption and emissions. These environmental concerns and possible energy security risks pose significant challenges for policy makers and opportunities for those involved in research, development, demonstration and commercialization activities tied to the introduction of alternative transportation fuels and other strategies to diversify fuel consumption.

Section 25604 of the Public Resources Code calls for the California Energy Commission (Commission) to "...describe energy development trends in the state, and evaluate the status of both new and existing technologies." The Transportation Technology Status Report (TTSR) presents a status of transportation technologies. Since transportation accounts for almost half of the state's energy use, it seems crucial that policy makers have a clear picture of the technology options in this area if they are to develop comprehensive energy policies. A lack of information about the negative aspects of transportation, and the options available to improve the system, currently impedes development and deployment of alternatives.

Transportation technology alternatives can provide additional opportunities such as reduced infrastructure costs, and economic development within the state. Seeking options that allow the state to maximize the benefits currently enjoyed from the transportation system, but also allow for improvements in energy security, environmental quality, and economic development, can help make the most of the state's resources.

The TTSR is a progress report of the commercial status of alternative fuel vehicle technologies and automotive fuel economy technology trends. The primary uses for the TTSR will be to:

- Identify and track which alternative transportation technologies offer the best opportunities for meeting California's transportation energy challenges

- Determine the commercial availability of transportation technologies for the purpose of developing transportation energy policy proposals

C Provide information for the Commission's Transportation Technologies Advancement Program (TETAP), for use in developing solicitations and helping to evaluate proposals

C Provide a database on transportation technologies with information about alternative fuel vehicles to assist in evaluating transportation energy policy proposals

C Track and evaluate the fuel economy-improving potential of many types of advanced technologies

C Develop a list of short-term and long-term transportation technology opportunities that are most beneficial to the state and are most worthy of public and private support

The use of alternative fuels offers opportunities for fuel substitution and emission reductions. Achieving these benefits is difficult, however, because a variety of factors inhibit the commercialization and market introduction of alternative fuel vehicles. A well-entrenched and established market and infrastructure for gasoline, the lack of infrastructure for alternative fuel vehicles, and an emerging alternative fuel vehicle technology and high costs all hinder alternative fuel vehicle commercialization. Recognizing these limitations, staff has identified some of the key challenges facing the development of alternative fuel vehicle technologies in Section I.

Beyond air quality and energy security benefits provided by alternative fuel vehicles, opportunities for improving the energy efficiency of California's transportation also exist. In fact, automobiles and light-duty trucks alone represent half of the state's transportation energy use, which in turn accounts for nearly 40 percent of all energy use in California and over 75 percent of petroleum use.

The state's large and growing vehicle population presents an opportunity to develop more fuel-efficient vehicles. Section II presents an evaluation of the potential for achieving higher average fuel economy for new light-duty motor vehicles. This section focuses on the status of automotive technology development related to further fuel economy improvements. Issues affecting the introduction of higher fuel economy vehicles into the marketplace also are discussed.

Section I - Commercial Status of Alternative Fuel Vehicles

The international automotive industry is engaged in widespread development activity involving applications of energy alternatives to conventional gasoline and diesel fuels. Original equipment manufacturer (OEM) companies in the United States, Asia, Europe and elsewhere are pursuing light-duty and heavy-duty vehicle projects using alcohol fuels (methanol and ethanol), compressed and liquefied natural gas, liquefied petroleum gas (propane), electricity and hydrogen. These projects range from initial vehicle and engine design and engineering phases, to prototype vehicle testing and preproduction demonstrations, to commercially available market options. In addition to this activity within the established OEM industry, a variety of outside entities are pursuing ventures involving the development and marketing of alternative fuel vehicles, including research and experimental vehicles, limited production specialty vehicles, and conversions of OEM models.

As part of the overall Transportation Technology Status Report (TTSR), this section summarizes the progress and status of alternative fuel vehicle (AFV) technology development projects worldwide for light-duty and heavy-duty highway motor vehicle applications. The key characteristics of each alternative fuel vehicle technology that affect prospects for marketplace introduction and success are described, along with the current status of the technology's commercial availability. Of particular interest are aspects of ongoing AFV technology development activities that affect the extent of potential opportunities for alternative fuel applications in California to help address the state's transportation energy goals of energy diversity and reduced petroleum dependence.

As a TTSR project activity, a detailed database has been created to inventory and track AFV projects of the worldwide OEM motor vehicle industry. The latest updated version of this database, which contains information on over 280 active and inactive AFV projects, comprises Appendix A. Included in this database are specific literature references for each entry, providing sources of more detailed information on the projects listed. The information used in the AFV technology status evaluations comprising the remainder of the report originates from the projects and references contained in this data base, along with the collective experience of more than 15 years of AFV research, development and demonstration activities by the California Energy Commission (Commission) staff in California.

An overview of alternative fuel development activity by the worldwide automotive industry is provided by the three following tables drawn from the above database. Table 1 is an industry-wide summary of AFV development projects undertaken to date for each fuel type. Individual manufacturer involvement in alternative fuels development to date is shown in Tables 2A (for light-duty vehicle manufacturers) and 2B (for heavy-duty vehicle and engine manufacturers). AFV development activities occurring outside the mainstream OEM auto industry are also surveyed as part of the TTSR project and, where they are seen as significantly affecting technology development status and opportunities for California application, such activities are included in the technology summaries for each alternative fuel.

TABLE 1: OEM INDUSTRY ALTERNATIVE FUEL DEVELOPMENT PROJECTS

Summary Of Projects Undertaken in the 1980s and 90s

	Methanol	Ethanol	Nat. Gas	LPG	Hydrogen	Electric
LIGHT-DUTY VEHICLES						
Commercially Available						
Models (in CA, 1997)	1	1	4			5
Additional Models w/						
Scheduled (US/CA) intro's		2	2	1		2
Models Available Only in						
Foreign Countries		2	4	7		10
Other Models Under						
Active Development		2	5	5	1	35
Inactive (or status uncertain)						
Development Models	33	3	10	1	7	41
Total Development Models						
Listed in Inventory	34	10	25	14	8	93
HEAVY-DUTY VEHICLES and ENGINES						
Commercially Available						
Models (in CA, 1997)		1	15	4		1
Additional Models w/						
Scheduled (US/CA) Intro's			5	1		
Models Available Only In						
Foreign Countries		1	3	2		
Other Models Under	1					
Active Development		1	14	7	3	20
Inactive (or status uncertain)						
Development Models	7	1	8			2
Total Development Models						
Listed in Inventory	8	4	45	14	3	23

Projects summarized are described in Appendix

TABLE 2A: ALTERNATIVE FUELS INVOLVEMENT OF OEM COMPANIES

Light-Duty Vehicle Manufacturers

Company	Methanol	Ethanol	Nat. Gas	LPG	Hydrogen	Electric
Audi	c					b (f)
Autolatina		a (f)				
BMW			a (f)		c	c
Chrysler	c	b	c	a (f)		a
Citroen			b (f)			
Daewoo			b (f)			b (f)
Daihatsu						a (f)
Fiat		a (f)		b (f)		a (f)
Ford	a	a	a	b		a
G.M.	c	b	b	b		a
Grumman						b
Honda	c		b			b
Hyundai	c				b (f)	b (f)
Kia						b (f)
Mazda	c		b (f)	a (f)	c	b (f)
Mercedes-Benz	c		a (f)		c	a (f)
Mitsubishi	c					b
Nissan	c			a (f)		a (f)
Opel						c
Peugeot						a (f)
Porsche	c					
Renault				b (f)		a, (f)
Saab	c					
Samsung						b (f)
Ssangyong						b (f)
Suburu	c					b (f)
Suzuki	c					c
Taylor-Dunn						a (f)
Toyota	c		a (f)	a (f)		a (f)
VW	c	c	a (f)			c
Volvo	c		b (f)			b (f)

Notes: a = one or more vehicle model(s) commercially available; b = active development project; c = inactive project or current status unknown; (f) = activity in foreign country

TABLE 2B: ALTERNATIVE FUELS INVOLVEMENT OF OEM COMPANIES
Heavy-Duty Vehicle and Engine Manufacturers

Company	Methanol	Ethanol	Nat. Gas	LPG	Hydrogen	Electric
APS						a
Blue Bird			a			b
BIA (Orion)			a			b
Bus Mfg. USA						b
Caterpillar	b		a	a		
Cummins	c		a	b		
DAF				a (f)		
DDC	c	a	a	b		
Deere			a			
El Dorado Ntl			b	a		b
Ford	c		c	a		
Flxible			c			
Freightliner			b			
G.M.			c			
Gillig			a			b
Hercules			c			
Isuzu			c			c
Kenworth			a			b
Mack			b			
MAN			a (f)	b (f)	b (f)	
Mercedes-Benz			a (f)	a (f)	b (f)	b (f)
Navistar	c		b			
Neoplan			b			b
New Flyer						b
Nissan			c			
Nordskog						c
Novabus					b (f)	b
Paccar			b			
Peterbilt			b			
RABA			b (f)			
Scania		a (f)				
Sisu				b (f)		
Specialty Veh Mfg						b
ThermoPower			a			
ThomasBuilt			c			b
Toyota						b (f)
Valmet				b (f)		
Vanhool			b (f)			b (f)

Notes: a = one or more engine and/or vehicle model(s) commercially available; b = active development project; c = inactive project or current status unknown; (f) = activity in foreign country

TABLE 2B: ALTERNATIVE FUELS INVOLVEMENT OF OEM COMPANIES
Heavy-Duty Vehicle and Engine Manufacturers

Company	Methanol	Ethanol	Nat. Gas	LPG	Hydrogen	Electric
Volvo		b (f)	a (f)			b (f)
Western Star				b,f		
Yuanwang						b (f)

Notes: a = one or more engine and/or vehicle model(s) commercially available; b = active development project; c = inactive project or current status unknown; (f) = activity in foreign country

A. METHANOL

1. Light-Duty Vehicles

a. *Industry Project Summary (see Table 3)*

The "big three" U.S. manufacturers (General Motors, Ford and Chrysler), Asian companies Honda, Toyota, Nissan, Mazda, Mitsubishi, Subaru, Suzuki (Japan) and Hyundai (Korea), and European companies Audi, Volkswagen, Mercedes-Benz, Porsche (Germany), SAAB and Volvo (Sweden) have all undertaken projects involving the development of methanol vehicle technology. The earliest projects (from the late 1970s through the mid-1980s) involved dedicated (methanol-only) vehicle technology. By the late 1980s, most activity became focused on flexible fuel vehicles (FFVs) capable of using gasoline and/or methanol in any combination.

Approximately two dozen methanol FFV passenger car and light-duty van models have thus far been demonstrated by 12 different auto companies, including 18 different models that have been demonstrated and/or tested by the Commission, the California Air Resources Board (CARB) and other public agencies in California. Of these, four models) Ford's Taurus, GM's Chevrolet Lumina, and Chrysler's Dodge Spirit/Plymouth Acclaim and Chrysler Concorde/Dodge Intrepid) have reached commercial availability. As of the 1996 and 1997 model years, however, the Ford Taurus is the only FFV model being offered for sale.

Several companies, including Ford, GM, Chrysler, Volkswagen, Nissan, Toyota and Subaru, have also carried out projects with dedicated methanol vehicle technology, with Ford and Volkswagen supplying vehicles for past Commission-sponsored dedicated methanol vehicle demonstration programs. GM, Toyota, Nissan and Volkswagen provided the most recent (1988-1992) examples of prototype or research vehicles designed to run on M-100 (100 percent methanol) or M-85 (85 percent methanol/15 percent gasoline).

Methanol is also being discussed as a potential on-board fuel source for fuel cell electric vehicles. However, none of the OEM fuel cell vehicle projects to date (described further in the electric vehicle section) are using this fuel.

b. *Commercial Availability Summary*

Most methanol vehicles released by OEM auto companies have been supplied for fleet use by government agencies and private companies in California. This activity began with twenty 1981 Volkswagen (dedicated methanol) Rabbits and pick-up trucks and forty 1981 (dedicated methanol) Ford Escorts, followed by 500 1983 Ford Escorts (also dedicated methanol). Since the advent of FFV technology, all additional methanol vehicles supplied by OEM companies have been FFVs, beginning with seven 1987 Ford Crown Victorias and twenty 1988 Chevrolet Corsicas provided for Commission-sponsored demonstration programs.

TABLE 3
METHANOL LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM COMPANIES

Company	Model	Status
Chrysler	E Dodge Spirit/Plymouth Acclaim FFV E LH Series (Concorde, Intrepid, Vision) FFV E Lebaron FFV (1989) E Voyager van FFV (1989) E Cirrus (1992)	E 93-94 market offering E 94-95 market offering E 10 vehicle demo (complete) E 10 vehicle demo (complete) E concept vehicle
Ford	E Taurus FFV E Econoline van FFV (1992) E Crown Victoria FFV (1987-89) E Escort (1983) dedicated E Mustang FFV (1993)	E 93-97 market offering E 200 vehicle demo (complete) E 90 vehicle demo (complete) E 500 vehicle demo (complete) E concept vehicle
GM	E Lumina FFV E Corsica FFV (1988)	E 1991-92 demo (complete) 1993 market offering E 20 vehicle demo (complete)
Honda	E Accord FFV (1992)	E concept vehicle
Hyundai	E Scoupe FFV (1991)	E concept vehicle
Mazda	E 323 Protege FFV (1990)	E single vehicle demo (complete)
Mercedes Benz	E 300SE FFV (1992)	E 5 vehicle demo (complete)
Mitsubishi	E Galant FFV (1990)	E 2 vehicle demo (complete)
Nissan	E NX1600 FFV (1991) E Stanza FFV (1989) E Sentra (1987-89) dedicated	E 16 vehicle demo (complete) E single vehicle demo (complete) E 2 vehicle demo (complete)
Saab	E 9000 FFV (1992)	E concept vehicle
Subaru	E Legacy (1991) dedicated	E single vehicle demo (complete)
Toyota	E Corolla FFV (1989-91) E Camry FFV & dedicated (1985-89) E Carina (1986) dedicated E Hilux Surf FFV (1989)	E 10 vehicle demo (complete) E limited demo (complete) E 2 vehicle demo (complete) E concept vehicle (complete)
Volkswagen	E Jetta FFV (1990-91) E Jetta (1990) dedicated E Rabbit and pick up (1981) dedicated	E 60 vehicle demo (complete) E concept vehicle E 20 vehicle demo (complete)
Volvo	E 740 & 940 FFV (1991)	E 10 vehicle demo

Methanol FFV demonstration programs in California continued with 1989 Ford Crown Victorias, 1990 Chrysler Lebarons, 1989 and 1991 Toyota Corollas, 1990 and 1991 Volkswagen Jettas, 1991 Nissan NXs, 1991 Volvo 740s and 940s, 1991 and 1992 Chevrolet Luminas, 1991 Ford Tauruses, 1992 Ford Econoline vans, and 1992 and 1993 Plymouth Acclaim/Dodge Spirits and Chrysler LH Series.

Earlier state-sponsored and private methanol vehicle fleet programs in California involved conversions of OEM gasoline vehicles to dedicated methanol operation. Several California companies, including Alcohol Energy Systems of Sunnyvale and Bill Stroppe and Son of Long Beach, provided such vehicle conversion services. Several large vehicle fleet operators, most notably The Bank of America and Sully-Miller Contracting Company of Long Beach, performed their own in-house conversions and operated methanol vehicle fleets during the 1980s. However, no methanol vehicle conversion projects have been reported in recent years, and there are no known companies currently offering methanol vehicle conversions.

The first public availability of methanol FFV models occurred in the 1993 model year, when GM offered the Chevrolet Lumina, Ford the 1993 Taurus and Chrysler the 1993 Dodge Spirit/Plymouth Acclaim as FFV options to fleet buyers and the public. These models are classified as "mid-size" passenger cars and were selected for introduction of an FFV option primarily because of the large numbers of these types of vehicles purchased annually by fleets. The U.S. Government has proved to be a major fleet customer for methanol FFVs, acquiring over 4,000 FFVs (nearly one-third of the production of the above three FFV models) in the 1992 through 1995 model years.

In the 1994 model year, Ford continued to offer the Taurus with an FFV option, and Chrysler the Dodge Spirit/ Plymouth Acclaim with an FFV option, while GM discontinued offering an FFV model. Mercedes-Benz, which had announced its intent to produce its 1994 300SE model as an FFV, canceled this plan, apparently due to failure to obtain the sought-after credit from the U.S. Environmental Protection Agency (EPA) on this model's "gas guzzler" tax. The Ford Taurus FFV was continued for the 1995 and 1996 model years and remains available for the 1997 model year. Chrysler, which discontinued the Dodge Spirit/Plymouth Acclaim FFV option in the 1995 model year, while adding FFV availability on its Chrysler Concorde/Dodge Intrepid model, has not offered an FFV since 1995. At this time, no other FFV model offerings from OEM companies, besides the Ford Taurus FFV, are officially scheduled, although both Ford and Chrysler are developing new ethanol FFV models that may also be adaptable to methanol use (see ethanol section for further details). To date, the four commercial methanol FFV model offerings described above have accounted for approximately 15,000 vehicles sold in California, mostly to fleets, and nearly all of these vehicles continue in operation. No dedicated methanol vehicle model has yet been commercially available, and no manufacturer has indicated plans to produce dedicated vehicles.

c. ***Summary of Technology Characteristics***

Based on the examples of methanol FFV technology that have reached commercial availability and achieved fleet application in California) namely the Ford Taurus, Chevrolet Lumina, Dodge Spirit/Plymouth Acclaim and Chrysler Concorde/Dodge Intrepid) the following are representative technology characteristics:

1. Unique Technical Features (compared to gasoline counterpart)

   Significant hardware modifications common to most methanol FFVs marketed to date include:

   - Fuel system components (fuel tank, fuel lines, fuel injector components, etc.) fabricated of materials resistant to methanol's corrosive and electrically conductive properties; stainless steel has typically been used for these components, although plastic fuel tanks have also been used

   - A somewhat larger-capacity fuel tank to help compensate for methanol's lower energy content (typically 18 - 20 gal. vs. 16 gal. for gasoline models)

   - Various methanol-specific internal engine components (depending on make/model) such as chrome plated piston rings and modified exhaust valve metallurgy

   - A special methanol sensing device, located in the fuel line, that continuously determines the methanol vs. gasoline content of the delivered fuel; several different types of sensing devices employing various fuel properties (refractive light index, electrical capacitance, etc.) have been used by different manufacturers

   - A modified engine control computer system capable of interpreting the signal from the fuel sensor and varying volumetric fuel flow and ignition timing as the fuel methanol percentage changes

   - Special high-capacity fuel injection system capable of delivering the higher fuel flows and the wide range of air/fuel ratios necessary for operation on methanol, gasoline and intermediate mixtures

   - Evaporative emission control system enhancements, including enlarged carbon canister, to handle higher fuel vapor volumes produced by some methanol/gasoline mixtures

   - Engine block heaters (an option on many gasoline vehicles) are used on some models to aid starting at very cold temperatures

- An "anti-siphon" device in the fuel fill neck to prevent siphoning of fuel from the tank (in recognition of methanol's higher toxicity if ingested)

- Special dashboard displays on some models showing existing fuel methanol content and/or estimated range to empty

- Special (colder range) spark plugs

- Distinctive emblems identifying the vehicle as an FFV

2. Different Operational or Performance Features (from gasoline counterpart)

Manufacturers have pursued the objective of FFV technology being as "invisible" as possible to the vehicle operator — i.e., minimal detectable differences when operating on methanol vs. gasoline. The most notable difference the operator will encounter is the need for more frequent refueling when methanol is used, typically about 60 percent more often when using M-85 (85 percent methanol, 15 percent gasoline) than when using straight gasoline. Intermediate combinations of methanol and gasoline in the tank will affect range proportionately. As noted above, most FFV models are equipped with larger-capacity fuel tanks to extend their refueling range. The refueling procedure is identical to that employed for gasoline vehicles, although existing methanol fuel station dispensers must be activated by electronic card-reader access systems employed to prevent misfueling gasoline vehicles with methanol. The dashboard display of methanol percentage is intended primarily to guide the driver's refueling plans, since a tank containing mostly methanol allows fewer remaining miles of driving than the same amount of fuel with a higher gasoline content.

Methanol's chemical properties have presented problems with maintaining adequate fuel quality in the distribution system, particularly during introductory times when the residence periods in fueling station storage tanks are long due to low pumping volumes. When methanol is allowed to react with certain incompatible material components in the distribution system, fuel contaminants can form and subsequently cause operational problems (such as clogged fuel filters) in vehicles. However, such problems appear to be avoidable once all components of the distribution system are made of materials compatible with methanol. Higher volumes of methanol throughput, resulting in shorter storage periods, would also help resolve these problems.

FFVs running on methanol also experience a measurable increase in horsepower compared with their gasoline-fueled operation, a difference that some drivers can detect in acceleration. The magnitude of this horsepower difference, however, while readily observable in dynamometer testing (typically measured at about 10 percent), is not likely to be highly perceptible to most drivers.

Fleet operators using methanol FFVs to date have reported that the most significant aspect of these vehicles in day-to-day fleet operations is the limited number of methanol fueling stations thus far in existence) approximately 50 public stations statewide, plus a number of on-site facilities operated by individual fleets. The practical implication of this limitation, however, is that FFV operators must simply refuel with gasoline as necessary, rather than face the hardship that would be posed by use of dedicated methanol vehicles. In fact, it appears that many in-use FFVs are being fueled more often with gasoline than with methanol. The previous realization that an adequate methanol refueling network will not be in place in the near-term was the primary reason for pursuing the initial market introduction of FFVs rather than dedicated methanol vehicles.

d. ***Maintenance and Reliability Features***

FFV models marketed to date have included the same warranty coverage as comparable gasoline models, with dealer service departments in most cases trained and equipped to handle all scheduled and unscheduled maintenance and repair functions. The early status of commercial FFV introduction has not yet provided for a definitive comparison of maintenance and repair frequencies between FFVs and their gasoline counterparts. However, several features of current FFV technology can be generally identified as contributing to extra (or unique) service requirements, including:

C Manufacturers' precautionary specification of shorter (typically 5,000-6,000 mile) oil change intervals, and (in some cases) use of special engine oils

C Incidents of fuel filter clogging or other service-requiring operational problems caused by occasional incidents of fuel contamination in the methanol distribution system

C Additional component failure modes represented by the unique methanol-related hardware components (e.g., fuel composition sensor, fuel pump, fuel injectors etc.)

C Potential service and repair delays resulting from limited stocking of unique methanol components or lack of familiarity on the part of some service departments

None of the above aspects of FFV maintenance is seen as a major handicap to current routine operation of FFVs, and all are becoming less prevalent as further market experience with FFV technology is acquired. Previous high-mileage demonstration experience with both FFV and dedicated methanol vehicle fleets tends to confirm long-term durability of methanol vehicle technology.

e. ***Emission Features***

Both Ford and Chrysler have certified their FFV models with the California Air Resources Board (CARB) as Transitional Low Emission Vehicles (TLEVs). The TLEV level, which must be met by a fraction of new vehicles sold in California to meet increasingly strict vehicle fleet average emission standards set by CARB, amounts to a non-methane organic gas (NMOG) emission rate of 0.125 grams per mile (gm/mi) or less, one-half the nominal NMOG standard. Numerous gasoline models from various manufacturers have also achieved TLEV certification. Methanol FFVs enjoy an emission certification advantage over gasoline vehicles, since CARB has determined that methanol NMOG emissions are much lower in atmospheric reactivity (less than one-half), and thus lower in ozone-forming potential, than gasoline NMOG emissions. Therefore, the measured NMOG value for a vehicle running on M-85 is adjusted downward by a "reactivity adjustment factor" of 0.41 for purposes of compliance with the emission standard.

The progressively tighter CARB emission standards will necessitate at least some new vehicles sold as Low Emission Vehicles (LEVs), meeting a NMOG level of 0.075 gm/mi and an oxides of nitrogen (NOx) level of 0.2 gm/mi. And beyond the year 2000, some Ultra Low Emission Vehicles (ULEVs), meeting an even lower NMOG level of only 0.04 gm/mile and a CO level of 1.7 gm/mi, will most likely be needed. The current FFV models have exhibited emission certification results (below those actually required for TLEV status) indicating likely capability to comply with the LEV requirement in future model years. Some gasoline vehicle models already have achieved certification as LEVs.

Formaldehyde emissions, which must also be controlled to very low levels to achieve TLEV/LEV status, have in the past been considered a problem for methanol vehicles, since methanol combustion produces considerably higher levels of formaldehyde than gasoline combustion. Progress in formaldehyde emission control is evident, with test results from current model FFVs which show formaldehyde within the TLEV/LEV standard of 0.015 gm/mi. In addition to exhaust emissions, emissions of fuel vapors are an increasing subject of automotive emission control attention, with methanol FFVs receiving special attention due to the higher volume of vapor produced by some gasoline/alcohol mixtures. Evaporative emission control systems on current FFV models are designed to maintain vapor emissions at allowable levels, however, with further in-use testing necessary to verify adequate control levels.

It is generally recognized that methanol FFVs, versus dedicated methanol vehicles, can achieve only part of the low-emission potential inherent in methanol fuel. This is because FFVs cannot be optimally engineered to take full advantage of methanol's combustion properties, since they must also be capable of gasoline operation. The U.S. EPA and others have advocated the continued development of dedicated (M-100) methanol vehicles, with the objective of fully achieving the low-emission potential of methanol in vehicles optimized for this fuel. Further research is necessary to address the various technical obstacles to automotive use of 100 percent methanol, including vehicle operational issues (e.g., cold-starting) and health and safety issues (e.g., flame luminosity). A more extensive methanol refueling network allowing unrestricted travel with dedicated methanol vehicles is an additional requirement. Meanwhile, progress with methanol FFV technology demonstrates the ability to keep pace with, and take advantage of, advances in gasoline vehicle emission control, providing an effective alternative fuel vehicle option for compliance with California's low-emission vehicle regulations.

Another category of vehicle emissions that continues to be evaluated for differences between gasoline and methanol vehicle characteristics involves toxic and carcinogenic substances. Gasoline exhaust and vapor emissions are sources of concern with respect to benzene and other toxic components, which are typically absent or at much lower concentrations in methanol exhaust and vapor, although formaldehyde (also a toxic air contaminant) is typically higher in methanol exhaust. Reductions in toxic emissions could prove to be one of the most significant emission advantages of methanol.

With respect to greenhouse gas impacts, total carbon emissions associated with methanol vehicles, based on the entire methanol-from-natural-gas fuel cycle (representative of all current methanol production) appear to be of roughly the same magnitude as those associated with use of petroleum-based gasoline. Production of methanol from coal, based on today's processes, would result in greater levels of carbon emissions, while biomass-to-methanol production options would potentially result in significantly reduced levels.

f. ***Fuel Efficiency Features***

As with emission optimization, FFVs do not allow complete advantage to be taken of methanol's higher inherent energy efficiency potential. For example, the use of higher engine compression ratios that can effectively employ methanol's higher octane rating are limited by the need to also burn gasoline. Nevertheless, FFV technology exhibited by the current models shows the capability for engine calibration to achieve measurably higher energy efficiency (on a British thermal unit [Btu] per mile basis) when running on methanol, while maintaining normal efficiency on gasoline. This helps offset a portion of the lower miles-per-gallon fuel economy and lower driving range per-tankful that results from methanol's lower energy content (approximately one-half the Btus of gasoline on a per-gallon basis), as well as reducing the per-mile fuel cost differential between methanol and gasoline.

Evaluation of fuel consumption test results for several FFV models indicates a combined "fuel substitution ratio" of 1.64 to 1, meaning that 1.64 gallons of M-85 are required, on average, to drive the same distance as one gallon of gasoline. This reflects about 8 percent higher energy efficiency on M-85 than on gasoline. Typical M-85 miles-per-gallon fuel economy in current model FFVs is 11.5 to 14 mpg, for a 20 gallon tank driving range of 230 to 280 miles, compared to standard model gasoline fuel economy of 19 to 23 mpg, for a 16 gallon tank driving range of 300 to 370 miles. Some projections show considerably higher efficiencies achievable with dedicated methanol vehicle technology, but remain unconfirmed due to the limited development focus on dedicated vehicles.

g. ***Cost Features***

The potential for cost differences associated with the ownership and operation of methanol FFVs versus comparable gasoline vehicles can be described in three categories: acquisition costs, fuel costs, and other operating costs. The three companies that have commercially offered FFV models, GM, Ford and Chrysler, adopted various market pricing practices, sometimes including an incremental price addition for the FFV option and sometimes pricing the FFV the same as its gasoline counterpart or even slightly lower. None of these companies have released a detailed breakdown of the actual additional costs involved in the production of the FFV models (including development costs), and thus a reliable estimate of the incremental unit cost of producing these vehicles is not available. Neither is the specific means employed by the manufacturers to recover the additional costs associated with FFV production fully understood, although presumably these costs are spread among overall vehicle model sales. The 1996 model year Ford Taurus FFV officially carried an additional price increment of about $1,200 above the gasoline Taurus "manufacturer's suggested retail price (MSRP)." However, fleets purchasing the Taurus FFV normally were able to obtain a manufacturer discount that largely (or totally) offset this price increment. For the 1997 model year, Ford officially priced the Taurus FFV at $1,165 above the gasoline version, but offered a factory discount of $1,510, allowing purchasers to realize a savings of $345, presumably in an attempt to spur sales of the FFV option.

The relative price of methanol fuel (marketed as M-85) and gasoline currently comprise the most significant component of the cost difference between methanol FFVs and gasoline vehicles. Current M-85 prices at the state-sponsored network of methanol fueling stations average $1.65 on a "gasoline equivalent" basis, or about 30 percent higher than the prevailing price of regular unleaded gasoline (the tax component of the prices of both fuels is essentially the same).

Thus, the typical operator of a current FFV would incur an additional cost of approximately 2 cents per mile when fueling with M-85 versus regular unleaded gasoline, or an addition to the annual vehicle fuel bill of about $300 for 15,000 miles of driving on M-85. Users of premium unleaded gasoline, which typically sells for at least 20 cents per gallon more than regular unleaded, would incur less of a fuel cost increase using methanol.

Other differential operating costs of current FFVs are considered relatively minor, since manufacturer warranties cover the cost of most unscheduled maintenance and repair that may be encountered with either an FFV or gasoline model for at least the first three years or 36,000 miles. The cost of more frequent oil changes, amounting to 1/2 cent per mile or less (or about 1 percent of typical overall vehicle per-mile ownership and operating costs), represents one identifiable extra maintenance cost. The possibility of extra service intervals for fuel system components (fuel pumps, fuel filters, etc.) affected by methanol also exists, but is not expected to add substantially to average FFV maintenance cost. Other significant components of total vehicle operating costs (e.g., tires, insurance, other routine scheduled maintenance items, etc.) are considered to be the same for FFVs and gasoline vehicles.

h. ***Challenges for Further Development***

The prospects for further development of methanol as a fuel for light-duty vehicles in California are currently clouded by a number of uncertainties. On one hand, methanol FFV technology has been widely demonstrated in the state through the cooperative efforts of state government and the auto industry. These efforts have resulted in the proven commercial readiness of methanol FFVs with in-use operating features closest to conventional gasoline vehicles of any alternative fuel technology demonstrated to date. Each of the "big three" U.S. auto makers has commercially offered at least one FFV model in the state, resulting in 15,000 of these vehicles currently in use.

Despite these significant technical successes, further development of methanol vehicles presently faces some serious challenges that leave methanol's future role as a motor fuel option unassured. Briefly summarized, the major issues that appear to be eroding the earlier development momentum for methanol as a fuel for light-duty vehicles include:

C OEM Vehicle Availability

While it was previously thought that auto makers would move to steadily increase their offerings of methanol FFV model options beyond the four models that have been made available to date, model availability has actually diminished to only one (the Ford Taurus) for the 1996 and 1997 model years. No additional OEM offerings of methanol FFV models have been announced, although Ford and Chrysler have announced plans for availability of ethanol FFV models (that could potentially be adapted to methanol as well) see ethanol section). Ironically, this declining availability of methanol models occurs just as a major mandate for AFV acquisition by fleets) federal Energy Policy Act regulations) has many fleet operators actively seeking alternative fuel model options.

C Vehicle Development Activity

Coupled with the decline in FFV model availability is a general industry trend of placing development efforts involving methanol vehicle technology "on hold." As noted earlier, most of the world's auto makers at one time pursued methanol vehicle development, with 18 different methanol FFV models submitted for demonstration and testing by California agencies. Currently, there is a notable absence of continuing methanol vehicle development activity, perhaps linked to a shifting emphasis to other alternative fuel technologies, such as electric and natural gas vehicles.

C FFV vs. Dedicated Vehicle Development

Originally, FFV technology was seen as a transition strategy, allowing methanol vehicles to enter the marketplace before a widespread methanol fuel station network was in place, since these vehicles could also fuel with gasoline when necessary. Dedicated (methanol only) vehicles were viewed as the ultimate technology goal, in order to allow optimization of methanol's emission and efficiency advantages and assure that methanol would actually displace gasoline. Past development efforts on behalf of dedicated light-duty methanol vehicle technology, both within the auto industry and by outside organizations (e.g., the U.S. EPA), all appear to have been discontinued.

- Fuel Price

Petroleum and gasoline prices have remained lower than past forecasts indicated, forestalling the price competitiveness methanol was expected to achieve. Complicating the picture have been wide fluctuations in the market price of methanol, with temporary price run-ups that have added to pessimism about the potential for competitiveness with gasoline. While world methanol prices are currently stabilized, and retail methanol fuel (M-85) prices are within 30 percent of regular unleaded gasoline prices, this price increment is still seen as a major constraint to the expanded commercial application of methanol. Future methanol fuel price trends are unpredictable, leaving considerable speculation as to when or if methanol will become competitive with gasoline.

- Fuel Supply

Related to the methanol vs. gasoline price dilemma is a growing concern that the worldwide methanol supply industry is not seriously pursuing the potential for a direct methanol motor fuel market. While vast potential to produce methanol is well documented, existing and planned world methanol production capacity of roughly 10 billion gallons per year, all based on natural gas as the feedstock, could supply only a tiny fraction of the motor fuel market. Supply development from alternative resources, such as coal and biomass, is not currently in evidence. Various factors, including prevailing low petroleum prices, corporate mergers and reorganizations, previous overly optimistic fuel market expectations that led to excess production capacity, and the decline in auto industry methanol vehicle offerings may all be contributing to the apparent backing away from motor fuel market development by the methanol industry. A particularly notable setback was the termination of plans that one large methanol producer had announced to begin setting up a network of methanol fueling stations throughout the U.S. Recent efforts by the Commission to maintain

industry participation and support for California's fledgling methanol fueling station network have also become increasingly difficult. In general, the industry does not appear to be taking the types of steps that would assure adequate methanol supply and distribution for the sustained growth of the motor fuel market.

- MTBE Market

Another significant factor in the methanol industry's level of interest in a direct motor fuel market may be the emergence of the gasoline additive methyl tertiary butyl ether (MTBE) as a major means of meeting new air quality-based oxygenated fuel requirements in

California and the rest of the U.S. MTBE production has quickly become one of the largest uses for methanol and, from the industry's standpoint, may represent a much more opportune avenue to enter the transportation energy market than the direct motor fuel option. Indeed, the continued success of MTBE as a methanol-based gasoline component may prove to be a key detriment to further development of methanol as a direct motor fuel alternative.

- Refueling Infrastructure

With only the bare beginnings of a methanol refueling network (55 public access and 42 private stations) in place in the state, the path to broader commercial availability of methanol for vehicle refueling remains highly uncertain. Neither the conventional (petroleum) fuel supply industry, the methanol industry, nor other private or public entities appear prepared to undertake the development of an adequate refueling infrastructure to support unlimited travel with methanol vehicles. The limited fuel volumes being pumped at most of the existing methanol stations, due largely to predominant use of gasoline in much of the on-road FFV fleet, does not make for a viable commercial proposition that would attract private investment capital for additional stations. Also, this contributes to continuing fuel quality problems. An earlier expectation that the alternative fuel station "trigger" embodied in state air quality regulations would require petroleum fuel suppliers to offer methanol at many of their gasoline stations now appears unlikely to have much effect.

- The Emission Picture

While originally pursued by the State of California primarily as an alternative form of (potentially coal-based) energy, methanol's low-emission potential became the major sustaining motivation for development of this fuel. More recently, however, continued OEM progress in reducing gasoline vehicle emissions, aided by the advent of reformulated gasoline, has diminished the emission advantage for methanol, especially that achievable with FFVs. Numerous gasoline vehicle models have been certified to CARB's Transitional Low-Emission Vehicle (TLEV) standard, and some to the even lower LEV level, demonstrating the auto industry's capability to achieve lower emission levels with gasoline than previously thought possible. Ultra-Low

Emission Vehicle (ULEV) standards will require even lower emissions that will prompt continued pursuit of low-emission technology options.   However, the potential role of methanol in auto manufacturer strategies for achieving further emission reductions appears uncertain at this time. Meanwhile, California's Zero Emission Vehicle (ZEV) mandate effectively directs the major OEM companies to focus resources on electric vehicle technology as the alternative fuel vehicle option specifically required to maintain air quality regulatory compliance in the state.

2. Heavy-Duty Vehicles

a. *Industry Project Summary (see Table 4)*

Five U.S. manufacturers of engines for heavy-duty motor vehicles) Detroit Diesel Corp., Caterpillar, Inc., Cummins Engine Co., Ford Motor Co. and Navistar International Transportation Co.) have been involved in methanol engine development, as has the German company MAN. Unlike light-duty automotive manufacturers, heavy-duty engine manufacturers typically supply engines to vehicle manufacturing companies which incorporate the engines in completed vehicles (with a few instances where companies manufacture both engines and vehicles). Thus, the methanol engines under various stages of commercial development by the above five companies have appeared in a number of different types of heavy-duty vehicles produced by different vehicle manufacturers. Vehicle applications that have received development attention include transit buses, school buses, utility trucks (refuse haulers, dump trucks, etc.), and over-the-road tractor-trailer trucks.

All heavy-duty methanol engines developed by the above companies to date have been dedicated to methanol operation, most using M-100 (100 percent methanol) with a small amount of a fuel additive for combustion and/or lubricity enhancement (the most popular being a brand name known as "Lubrizol"). M-85, with or without a fuel additive, is used in some engine/vehicle applications. Some engine/vehicle applications, however use M-85. One project undertaken by Caterpillar, under sponsorship of the U.S. Department of Energy, aimed at developing a methanol/diesel fuel flexible engine. Various other projects have been undertaken, involving OEM companies as well as companies outside the OEM industry, to partially fuel diesel engines with methanol (along with diesel fuel) in a mode known as "fumigation."

b. *Commercial Availability Summary*

Only one heavy-duty engine manufacturer, Detroit Diesel Corp (DDC), has offered a methanol engine for commercial sale in the U.S. and California, mainly for use in transit buses. The methanol version of DDC's 6V-92TA engine, the most widely-used transit bus engine in the U.S. to date, was the first alternative fuel, heavy-duty engine to achieve emission certification by CARB and U.S. EPA. This methanol engine was used in 333 transit buses, most built by Transportation Manufacturing Corp. (TMC), purchased by the Los Angeles County Metropolitan Transportation Authority (LACMTA) from 1988 to 1992.

TABLE 4
METHANOL HEAVY-DUTY ENGINE/VEHICLE DEVELOPMENT
BY OEM COMPANIES

Engine	Vehicle Manufacturer & Type	Status
Caterpillar (3306 DITA)	E Peterbilt, refuse truck	E single vehicle demo
Cummins (L-10)	E Gillig, transit bus E Peterbilt, dump truck	E two vehicle demo E single vehicle demo
Detroit Diesel (6V-92TA)	E TMC, transit bus E Carpenter, Crown Coach school buses E GMC, transit bus E GMC, sludge hauler E Freightliner, truck tractor	E past commercial offering E past commercial offerings E 14 vehicle demo E single vehicle demo E single vehicle demo
Detroit Diesel (6L-71TA)	E Volvo-White, refuse truck E Freightliner, truck tractor	E two vehicle demo E single vehicle demo
Ford	E Ford F-800, delivery truck	E single vehicle demo
Navistar	E International, utility truck	E single vehicle demo

LACMTA has since converted most of these buses to use ethanol instead of methanol in an attempt to improve their reliability, and is considering converting the remaining methanol buses to ethanol as well. Four additional transit buses, built by General Motors, also with the DDC methanol engine, were purchased by the Riverside Transit Agency and South Coast Area Transit. Another transit agency, Golden Gate Transit, operated the first bus with the DDC methanol engine, along with another methanol bus from MAN, in a previous demonstration project that began in 1983. Also, 150 school buses with the DDC methanol engine, built by Crown Coach and Carpenter Corp., are being operated by various school districts in the state as part of the Commission's Safe School Bus Clean Fuel Efficiency Demonstration Program. Including all demonstration and production engines operated outside California, approximately 560 of the DDC methanol engines were ordered. DDC, however, is not continuing to offer its methanol engine for sale at this time, apparently due to a lack of continuing market demand and the company's decision to retire the two-cycle 6V-92 engine in favor of four-cycle diesel engine technology which has yet to be adapted for methanol use.

All five of the above heavy-duty engine manufacturers have been involved in a methanol truck demonstration program sponsored by the Commission and the South Coast Air Quality Management District. Methanol engines from these five companies are being, or have been operated in nine heavy-duty trucks of various makes, including Peterbilt, Freightliner, GMC, Ford, International and Volvo/White, as part of this demonstration.

The Caterpillar/U.S. DOE flexible fuel (methanol/diesel) engine project involved testing conducted on a single-cylinder (laboratory) research engine, accompanied by bench testing of sensors for diesel/methanol mixtures. The methanol/diesel fumigation concept did not proceed to the point of serious development activity.

c. ***Summary of Vehicle Technology Characteristics***

Heavy-duty engine and vehicle manufacturers have proven the feasibility of adapting diesel bus and truck engines and fuel systems to use methanol. Transit bus service at LACMTA shows that methanol buses can meet the same duty cycle requirements as diesel buses, although the district has experienced a higher out-of-service rate for unscheduled maintenance of its methanol bus fleet than for its diesel buses. The extra space available on bus undercarriages generally allows for installation of extra fuel tank capacity to provide the needed vehicle refueling range using methanol.

The major remaining technical issue associated with heavy-duty methanol vehicle applications is engine reliability and durability. Transit operators and other users of heavy-duty vehicles have come to rely on the high reliability and long-term engine durability provided by today's diesel engines, which have yet to be demonstrated by heavy-duty methanol engines.

LACMTA has encountered engine problems that require early engine overhauls on many of its methanol buses, adding to the operating cost and decreasing the availability of the district's methanol fleet. At this time, it is uncertain whether methanol engine developers will continue to pursue the further technology development necessary to improve methanol engine reliability and durability to match that of diesel engines.

From an emission standpoint, heavy-duty vehicle applications of methanol have demonstrated excellent characteristics, with NOx and particulate emissions generally about one-half that of the best diesel technology. These demonstrated emission levels, especially for NOx, which poses a particular compliance dilemma for diesel engine vehicles, provided the major impetus for OEM development of heavy-duty methanol vehicle technology. At the same time, however, heavy-duty engine manufacturers have found means of improving diesel engine emissions, to the point where newly-adopted state and federal transit bus emission standards are being met with new diesel-fueled buses, something that was previously believed to be unachieveable. Total fuel cycle carbon emissions associated with methanol use in place of diesel fuel appear to be similar or slightly higher, based on natural gas-based methanol production and current methanol versus diesel engine efficiencies.

The overall fuel efficiency of methanol in heavy-duty vehicle applications takes advantage of most of the high efficiency of diesel-fueled engines. While reported efficiencies continue to improve with refinements of engine designs, the best results to date show methanol engine efficiency to be about 5 percent lower than for diesel counterparts. This results in a fuel substitution factor of about 2.3 to 2.5 gallons of methanol required to travel the same distance as one gallon of diesel fuel.

Higher costs in all three major categories) vehicle acquisition, fuel and maintenance) combine to make methanol a more expensive option than diesel for current heavy-duty vehicle applications. For transit buses such as those operated by LACMTA, which typically have a purchase cost of between $200,000 and $300,000 and an annualized cost (including depreciation, operation and maintenance) of around $70,000 to $75,000, substituting a methanol bus costs about 10 percent (around $20,000) more for initial purchase. Annualized cost for the methanol bus, including the higher costs of fuel and maintenance, would be an estimated $7,000 to $12,000 more than a diesel bus. Provisions for mobile emission credit trading adopted by CARB offers a means for transit districts and other heavy-duty vehicle operators to substantially offset this additional cost of alternative fuel vehicle purchase and operation by attaching a tradable value to the reduction in NOx emissions beyond that required by emissions standards, an approach that has been employed by LACMTA.

d. ***Challenges for Further Development***

Much of the earlier discussion of challenges for further development of light-duty methanol vehicle applications is similarly applicable to methanol use in the heavy-duty vehicle sector, with the following additional comments:

C The commercial availability and development activity picture for heavy-duty methanol vehicles/engines is currently even less promising than for light-duty vehicles. Only one heavy-duty methanol engine model has thus far reached commercial availability, and it is no longer being offered. Without some type of further inducement, it is not certain that OEM companies intend to pursue additional model development.

C Heavy-duty methanol engine development has employed two-stroke diesel engine technology (the DDC 6V-92 engine), whereas all new diesel-fueled engines now employ more efficient four-cycle technology. For methanol to make further progress as a heavy-duty engine fuel, with prospects for competing with diesel-fueled engines in a wide range of markets, methanol engine development involving four-cycle diesel engine designs will likely be necessary. To date, there has been minimal OEM corporate development activity with methanol-fueled four-cycle diesel engine adaptations.

C While the issue of FFV vs. dedicated vehicle technology does not affect the heavy-duty outlook (since virtually all heavy-duty methanol vehicle/engine development has concentrated on dedicated technology), there are other important decisions facing heavy-duty methanol technology development, such as the pursuit of four-cycle methanol engine technology and the role of further methanol engine development as an emission control strategy. As with light-duty vehicles, progress in controlling emissions using petroleum fuels has rendered the air quality advantage for methanol less compelling.

C The cost factor is somewhat more of an obstacle for heavy-duty applications, since the cost differential for both fuel and vehicles remains wider between methanol and diesel than between methanol and gasoline, and because heavy-duty vehicles have high fuel usage.

C The overall fuel supply issues are similar for the heavy-duty and light-duty methanol motor fuel markets. However, concern over an adequate refueling network is somewhat lessened by the predominance of on-site fleet refueling facilities in the heavy-duty sector (with the exception of over-the-road trucking, which poses a difficult case for methanol refueling access).

B. ETHANOL

1. Light-Duty Vehicles

a. *Industry Project Summary (see Table 5)*

Three of the world's major auto companies, Ford, GM, and Volkswagen, have produced multiple models of dedicated ethanol passenger cars and light-duty trucks in Brazil since 1980. Over four million vehicles using 95 percent ethanol, most produced as new alternative fuel vehicles by the domestic auto industry, are in service in Brazil, representing about one-third of the country's vehicle fleet. In addition, most gasoline sold in Brazil is a 22 percent ethanol blend. Brazil's use of ethanol, which comprises the most extensive national program to introduce an alternative fuel to date, originated from that country's decision, in the wake of the 1979 oil crisis, to reduce its petroleum dependence by using energy produced from domestic agricultural (sugar cane) resources.

The manufacture of ethanol versus gasoline and diesel vehicles has fluctuated greatly from year to year with the Brazilian government's market intervention, involving repeated manipulation of fuel and vehicle prices. In recent model years, emphasis has again shifted from production of ethanol models to vehicles using ethanol blended gasoline, in contrast to past years when ethanol vehicles were produced almost exclusively. Few Brazilian ethanol vehicles have apparently ever been exported, and the likelihood of ethanol models from Brazil being marketed in the U.S. appears minimal.

California's Alcohol Fuels Demonstration Program at one time included demonstrations of ethanol as well as methanol vehicles, including twenty 1981 Volkswagen Rabbits and pick-up trucks produced as new dedicated ethanol vehicles by VW of America. These vehicles generally demonstrated comparable technical operating acceptability to their methanol counterparts in this program, which subsequently discontinued involvement with ethanol due to its relatively higher cost than methanol and the logistical difficulties of operating two separate alcohol fuel distribution systems.

TABLE 5 ETHANOL LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM AUTO COMPANIES		
Company	**Model**	**Status**
Ford	E Crown Victoria (1989-91) FFV E Taurus FFV E Ranger pickup FFV E Windstar Van FFV E Various models in Brazil	E 9 vehicle demo (complete) E 112 vehicle demo in Midwest (complete); current commercial offering E 1998 production planned E demo in Midwest E commercial production
GM	E Chev. Lumina FFV (1992-93) E Chev. S-10/GMC Sonoma pickup FFV E Various models in Brazil	E 50 vehicle demo in Midwest (completed); commercial offering in 1993 model year E previously under development E commercial production
Chrysler	E Dodge Caravan/Plymouth Voyager	E 1997 production planned
Volkswagen	E Rabbit, pick up (1981) E Various models in Brazil	E 20 vehicle demo (complete) E commercial production

More recently, the advent of FFV technology in the U.S. has resulted in demonstrations of FFVs with ethanol by GM and Ford, and commercial offerings of ethanol FFVs by both companies. Most components of FFV technology, while engineered primarily for methanol/gasoline operation, appear to be equally adaptable to ethanol/gasoline operation. U.S. ethanol interests, as well as several midwestern (ethanol-producing) states and the federal government, have participated with OEM companies in demonstrations of ethanol FFVs. Ford supplied nine 1989 and 1991 Crown Victoria FFVs for ethanol demonstrations; some of these were vehicles obtained by a California organization, the California Renewable Fuels Council. GM supplied fifty 1992 Chevrolet Lumina FFVs for ethanol demonstrations conducted by the states of Illinois and Wisconsin and the U.S.

Department of Energy. Ford has conducted a demonstration of 112 Taurus FFVs with ethanol in midwestern states, and now commercially offers this model. GM was recently pursuing development of its Chevrolet S-10/GMC Sonoma pickup series as an ethanol FFV although plans for this option are now on hold. Most recently, Ford announced plans to offer its Ranger pickup as an ethanol FFV in 1998, and Chrysler announced the planned offering of its popular minivan series as ethanol FFVs in 1998.

b. ***Commercial Availability Summary***

GM offered the 1993 Chevrolet Lumina FFV for ethanol (as well as methanol) use, and sold approximately 375 of the ethanol versions, comprising the first commercial market offering of an OEM ethanol vehicle in the U.S. With GM's discontinuation of the Lumina FFV, no ethanol-capable model was available in the 1994 and 1995 model years. Ford has now begun officially offering the Taurus FFV for ethanol (as well as methanol) use in the 1997 model year. The Ford and Chrysler models noted above are expected to add to ethanol FFV model availability for the 1998 model year.

c. ***Summary of Vehicle Technology Characteristics***

Current FFVs using ethanol have mostly identical technical characteristics to those previously summarized for methanol FFVs, with the following noteworthy exceptions:

- Ethanol's higher energy content (about one-third more Btus per gallon than methanol) results in more miles per gallon and a lower fuel substitution ratio (estimated at about 1.34 gallons E-85 to one gallon gasoline) and proportionately greater refueling range.

- Ethanol's somewhat less corrosive chemical properties compared to methanol may contribute to somewhat lower maintenance and service requirements.

- While the Ford Taurus ethanol FFV is certified as meeting nominal California emission standards, no ethanol FFVs have applied for or attained California TLEV status as have methanol FFV models.

- Greenhouse gas implications of ethanol use as motor fuel remain controversial, with today's corn-based ethanol fuel cycle (using fossil fuel inputs) apparently resulting in only modest reduction of carbon emissions compared to the gasoline fuel cycle. Other ethanol production concepts relying more completely on renewable biomass resources could, however, involve much lower levels of greenhouse gas emissions.

- Ethanol, currently a more expensive fuel than methanol, is not available at any fuel stations in California. Thus, FFV operation on ethanol involves higher operating cost and presents more difficult refueling logistics than methanol operation.

d. ***Challenges for Further Development***

Ethanol continues to be used as a gasoline blending component throughout the U.S., to the extent of over one billion gallons per year, spurred by a federal tax subsidy and air quality regulations requiring oxygenated gasoline. As a direct motor vehicle fuel, however, ethanol has yet to achieve a significant role in the U.S. (as it has in Brazil), although its base of support among Midwest agricultural interests continues to pursue such an objective. The major issues affecting the potential for commercial application of ethanol as a direct motor fuel for light-duty vehicles in the U.S. are:

- Fuel Cost

  Ethanol continues to be the most expensive to produce of any of the available alternative fuel options. Although limited progress in reducing production costs is being made, ethanol remains much more costly to produce than gasoline at today's petroleum prices.

- The Subsidy Controversy

  For years, ethanol has benefited from a controversial federal tax subsidy that has allowed it to compete in the motor fuel market but, at the same time, created an air of uncertainty regarding its future market viability. Continued threats in Congress to remove the subsidy, and criticism from opponents of the subsidy, serve to create instability for the ethanol vehicle option.

- The Energy Efficiency Issue

  Ethanol critics have exploited characteristics of the traditional U.S. corn-based production system to argue that ethanol uses more energy (in the form of fossil fuels) to produce than it delivers. While not necessarily accurate or representative of ethanol production options generally, such claims have had a negative effect on support for ethanol.

- Emission Questions

  Related to the efficiency issue are contentions that ethanol would exacerbate (or at least not help solve) global warming, even though ethanol produced in a fully biomass-based fuel cycle could actually offer one of the most effective greenhouse gas control options. Also, testing of ethanol vehicles for conventional criteria emissions has not been as extensive as for methanol and other alternative fuels, thus the potential air quality benefits of ethanol are not as well established. CARB has yet to formally assign ethanol a reactivity adjustment factor, a necessary component to determining the relative ozone-forming effect of this fuel.

- Fuel Supply

  As with methanol, current ethanol supply capacity represents only a small fraction of transportation energy requirements, and the prospects for major expansion of this capacity to meet a larger share of motor fuel demand are uncertain. While the Brazilian case provides a significant example of large-scale gasoline substitution with ethanol, its implications are controversial and its applicability to U.S. conditions is questionable. The potential for a greatly expanded biomass-to-ethanol industry (in the U.S. or elsewhere) adequate to serve a larger portion of the country's motor fuel needs has yet to be proven.

- Refueling Infrastructure

  A fuel distribution network for ethanol in California has yet to be undertaken, even to the initial extent achieved for methanol. The existence of some ethanol refueling facilities in midwestern states (and previous facilities that operated in California) demonstrates such facilities can be installed and operated in virtually the same manner as methanol facilities. Plans do not indicate pursuing such activity.

- Vehicle Availability

  As with methanol, current availability of OEM ethanol vehicles is limited to the Ford Taurus FFV for the 1997 model year. Expanded availability of OEM models is necessary for ethanol to play a greater role as a direct motor fuel alternative. Recent announcements by Ford and Chrysler reveal the upcoming availability of at least two new models.

- Vehicle Technology Development

  Another similarity with methanol is the absence of development activity on behalf of dedicated (vs. FFV) ethanol vehicle technology. Both forms of alcohol fuel offer their full emission and efficiency advantages only in optimized, dedicated vehicles, although there may be common technology development paths that could lead to dedicated vehicle technologies for both fuels. The nascent state of alcohol refueling infrastructure, however, continues to be cited by the auto industry as constraining development of dedicated vehicles.

2. Heavy-Duty Vehicles

a. *Industry Project Summary (see Table 6)*

Detroit Diesel Corp. (DDC) and two Swedish companies, Volvo and Scania, have undertaken heavy-duty ethanol engine development. DDC has provided ethanol-fueled versions of its highly successful 6V-92TA engine (also adapted for methanol use) for transit bus, school bus and truck applications in several midwestern U.S. and Canadian locations. Volvo and Scania are providing vehicles for ethanol-fueled, heavy-duty vehicle demonstrations in Europe.

TABLE 6 ETHANOL HEAVY-DUTY ENGINE/VEHICLE DEVELOPMENT BY OEM COMPANIES		
Engine	**Vehicle Manufacturer & Type**	**Status**
Detroit Diesel (6V-92TA)	E TMC, transit bus E Truck	E being used in transit buses at L.A. Co. MTA E 5 vehicle demo
Scania	E Scania, transit bus	E 30 vehicle demo (Sweden)
Volvo	E Heavy duty vehicles	E 18 month test program

b. ***Commercial Availability Summary***

DDC has thus far supplied ethanol engines for 21 transit buses, including a 14-bus demonstration program in Peoria, Illinois, using buses built by TMC. Five more ethanol engines are installed in trucks being demonstrated in Illinois and Colorado. DDC apparently developed the ethanol version of the 6V-92 engine to the point of production readiness, along with the methanol version, having achieved CARB emission certification with this engine on both alcohol fuels. As previously noted for the methanol version, DDC's move to four-cycle diesel engine technology leaves the further commercial availability of the ethanol version of this engine uncertain. As noted earlier, Los Angeles County MTA is converting from methanol to ethanol use in its alcohol-fueled transit bus fleet employing the DDC 6V-92 engine. The Scania ethanol engine is apparently available in Europe, but there are no known plans to market either the Scania or Volvo engines in the U.S.

c. ***Summary of Vehicle Technology Characteristics***

Relatively little field experience has been acquired with the DDC ethanol engine thus far to compare operating characteristics with its methanol or diesel counterparts. However, some aspects worth noting include:

C Emission data reported by DDC for the ethanol engine show very low particulate matter emissions, but do not yet demonstrate the dramatic NOx reduction achieved by the methanol version. More verification will likely be needed to determine the extent of emission benefits achievable with ethanol versus methanol. The DDC

ethanol engine, fueled with E95 (95 percent ethanol, 5 percent gasoline), has been certified as meeting strict urban bus emission standards by both CARB and EPA.

C Ethanol fuel efficiency, like methanol fuel efficiency, appears to be somewhat lower than for diesel-fueled engines, although ethanol's higher energy content than methanol results in a lower fuel substitution ratio (about 1.7 to 1.9 gallons of ethanol to travel the same distance as on one gallon of diesel fuel).

- The higher cost of ethanol fuel compared with methanol means that heavy-duty ethanol vehicle operation could be even more expensive (versus diesel fuel) than that reported for methanol operation. In cases where ethanol suppliers can apply the federal ethanol tax subsidy, the net cost of ethanol to the user may be comparable to or below the cost of methanol.

- Ethanol may pose less severe engine operating conditions than methanol, somewhat reducing the engine reliability/durability concerns remaining with methanol. This appears to be the primary reason for LACMTA's ongoing changeover from methanol to ethanol.

d. ***Challenges for Further Development***

Most of the perspective provided earlier for challenges for further development of ethanol as a light-duty vehicle fuel applies equally to heavy-duty applications, with the following additional comments:

- The current high cost of ethanol is an even greater factor in heavy-duty applications, given the lower cost of fueling with diesel than with gasoline, and the high-volume fuel consumption of heavy-duty vehicles.

- As with heavy-duty methanol vehicle/engine technology, only one U.S. OEM (DDC) has pursued ethanol engine development to the point of commercial readiness, and there is little indication that further OEM activity is intended at this time.

C. NATURAL GAS

1. Light-Duty Vehicles

a. ***Industry Project Summary (see Table 7)***

GM, Ford and Chrysler have been involved in the development of compressed natural gas (CNG) light-duty vehicle models. Japanese automakers Honda, Toyota and Mazda,

TABLE 7
NATURAL GAS LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM AUTO COMPANIES

Company	Model	Status
BMW	E 316g, 518g	E available in Germany
Chrysler	E Dodge B-350 Ram/Van Wagon E Dodge Caravan E Dodge Ram Pickup E Dodge Dakota Pickup	E 1992-96 market offering (not currently available) E 1995-96 market offering (not currently available) E 1995-96 market offering (not currently available) E previous development
Citroen	E BX	E demo in France
Daewoo	E Espero Sport Sedan E Cielo	E under development E prototype
Ford	E Crown Victoria E F-Series pick up E Econoline Van E Contour	E 1996-97 market offering E 1997 market offering E 1997 market offering E 1997 offering as "QVM" vehicle
General Motors	E Sierra pick up E Chevrolet & GM Full-Size Pickup E Caprice E Corsica	E 2,500 vehicle demo (93-94) (canceled; vehicles recalled) E intro. in 1997 as 1998 model E previous development E previous development
Honda	E Civic E Accord	E ongoing demonstration; planned intro. as 1998 model E concept vehicle (1992)
Mazda	E Titan pickup	E prototype (1995)
Mercedes Benz	E T-1 Van	E available in Europe
Toyota	E Corolla Van	E available in Japan
Volkswagen	E T-4 transporter	E available in Europe
Volvo	E 850	E ongoing demonstration

the South Korean company Daewoo, and European manufacturers BMW, Citroen, Mercedes Benz, Volkswagen and Volvo have also initiated light-duty CNG vehicle development projects. Liquefied natural gas (LNG) has not received OEM development attention for light-duty vehicle applications, although LNG technology is the focus of a number of heavy-duty vehicle projects (see subsequent section).

To date, about twenty-five different passenger car, pick-up truck and van models have been included in the aforementioned companies' CNG development activities. Ford's CNG vehicle development models are the Crown Victoria (dedicated CNG) large passenger car, the Contour (bi-fuel CNG/gasoline) compact passenger car, the F-Series full-size pick-up truck, and the Econoline full-size van (dedicated models). Chrysler has developed CNG versions of the Dodge B-250/350 Ram Van and Wagon, the Dodge Ram (full-size) pickup truck, and the Dodge Caravan/Plymouth Voyager minivan, all dedicated CNG vehicles. GM has undertaken applications of CNG with the Chevrolet Caprice and Corsica (large and compact) passenger cars, the GMC/Chevrolet full-size pick-up truck, and the GMC/Chevrolet full-size (cargo and passenger) van.

Honda has focused its natural gas efforts on the Civic and Accord passenger car models, applying dedicated CNG technology. Mazda has unveiled a dedicated CNG version of its T-Series compact pickup. BMW is developing bi-fuel CNG/gasoline models based on its 316i, 518i and 740i passenger car models. Volvo's effort involves a dedicated CNG version of the 850 passenger car model. Mercedes Benz, Volkswagen and Toyota have all pursued development of CNG van models, and the French company Citroen has developed a CNG passenger car prototype.

A number of automotive equipment suppliers outside the major OEM vehicle industry are also engaged in the development of component technologies for CNG vehicle fueling. These companies supply natural gas fueling systems for vehicle conversion applications as well as for use on OEM-produced vehicles. An "in-between" approach involves joint ventures in which OEM companies utilize outside "upfitters" to perform the alternative fuel system installation under manufacturer auspices.

b. ***Commercial Availability Summary***

Chrysler was the first OEM company to begin a commercial CNG vehicle offering with the Dodge Ram Van/Wagon, producing some customer-ordered units in 1992 after conducting an earlier demonstration program. Chrysler expanded its CNG model offerings in 1994 with the Dodge Caravan/Plymouth Voyager minivan and in 1995 with the Dodge Ram full-size pickup, continuing to produce CNG models through the 1996 model year, with cumulative sales of approximately 4,000 vehicles. The company has placed its CNG vehicle production plans on hold, however, with no offering scheduled for the 1997 model year, citing low market demand and the high cost of CNG fuel cylinders as the key factors.

GM partially completed a large-scale commercial fleet program resulting in 2,500 pick-up trucks with CNG fuel systems installed by a Michigan upfitter company, PAS Inc., but this program was ended prematurely and the vehicles recalled by GM due to failures of CNG storage cylinders on several of these vehicles. GM's CNG vehicle development efforts were temporarily "on hold," but the company has undertaken development of a new CNG pickup model for planned introduction late in 1997.

Ford introduced its Crown Victoria CNG model in the market place in the 1996 model year, and expanded its CNG model offerings for the 1997 model year, adding the F-Series full-size pickup truck and the Econoline van to its line of dedicated CNG vehicles. In addition, Ford is offering a bi-fuel CNG/gasoline version of its Contour compact passenger car model, utilizing outside upfitting companies contracted via its "Qualified Vehicle Modifier Program" to upfit these vehicles according to manufacturer specifications. Honda has announced plans to introduce the Civic GX CNG model by 1999.

In Europe, BMW has initiated limited commercial production of CNG versions of the 316g and 518g passenger cars, and both Mercedes Benz and Volkswagen have begun offering CNG van models. In Japan, Toyota has announced the initial offering of a CNG version of its Corolla van. Honda is involved in a 13-vehicle demonstration of its Civic CNG model in fleets, some in California, and has indicated intentions of offering this vehicle commercially in the U.S. sometime in 1997. Mazda is testing a prototype of its CNG pickup model, and Daewoo is undertaking development of two of its passenger car models. Volvo is conducting a demonstration of its CNG vehicle model in Sweden and the U.S.

In addition to the above OEM CNG vehicle development activities, several aftermarket automotive companies have offered conversions of gasoline vehicles to either dedicated or bi-fuel CNG operation. Table 7A lists companies who have obtained CARB certification as suppliers of CNG vehicle conversion systems in California in past model years. Some of these companies, and/or vehicle upfitters installing these companies' certified kits, have supplied CNG vehicle conversions to major fleet operators, including California natural gas utilities, U.S. Government fleets and others. At this time, however, there are no new (1997) vehicle models with conversions available in California under new, more restrictive CARB certification regulations that took effect in 1996.

Estimates of the worldwide population of CNG vehicles (about half a million) and the U.S. population (about 30,000) apparently continue to be comprised mostly of converted vehicles. Countries with the most in-use CNG vehicles (Italy, Australia, Canada) have relied totally on vehicle conversions, with no known assembly line production of OEM models. However, the limited availability of OEM models in the California new vehicle market is currently replacing the conversion option as the only existing source of CNG vehicles. Most of the CNG vehicles operating in California thus far (an estimated 4,000 vehicles) are in natural gas utility company fleets or other fleets that the gas companies have facilitated.

TABLE 7A CARB-CERTIFIED SUPPLIERS OF CNG VEHICLE CONVERSION SYSTEMS (for 1994 & later model year light-duty vehicles, as of Aug. 1997)
Baytech Corp., Los Altos, California (for 1 GM 1995 engine family)
GFI Control Systems, Inc., Ontario, Canada (for 6 GM, 5 Ford & 3 Chrysler 1994 engine families; 4 GM, 2 Ford & 2 Chrysler 1995 engine families; 2 Ford 1996 engine families)
Impco Technologies, Inc., Cerritos, California (for 5 GM & 3 Ford 1994 engine families)

c. ***Summary of Vehicle Technology Characteristics***

Based on the various models of Ford, Chrysler, and GM CNG light-duty vehicles that have been sold or demonstrated in California to date, the following are considered to be representative technology characteristics:

1. Unique Technical Features (compared to gasoline counterpart)

   The major hardware features distinguishing current CNG vehicle technology from gasoline vehicles include:

   - CNG fuel storage cylinder(s) in place of (for dedicated vehicles) or in addition to (for bi-fuel vehicles) the gasoline fuel tank. While past technology involved steel cylinders, newer technology cylinders, supplied by aftermarket specialty tank manufacturers, are comprised of an aluminum inner shell reinforced with an outer composite fiber wrap, which are filled to 3,000 psi pressure. Emerging technology cylinders of all-composite construction are being demonstrated. Tank mounting locations vary on different models, and include undercarriage, passenger car trunk and pickup truck bed locations, with special enclosures or shields used on some models to protect tanks from exhaust heat, rocks, etc.

- CNG fuel fill system (in place of or in addition to gasoline fill system). All models employ a type of pressure fitting receptacle for the CNG dispenser nozzle, most located inside the conventionally located fuel fill door.

- CNG fuel pressure regulator(s) to reduce tank pressure to proper operating fuel pressure, and CNG fuel lines (typically teflon-lined braided stainless steel hose line) from tank to engine, all located on vehicle undercarriage (in place of or in addition to gasoline fuel lines and fuel pump). Regulator(s) typically have an auxiliary heating system that employs engine coolant. Some designs employ a special type of fuel filter to remove any water, particles or oil (i.e., from the compressor) from the fuel. The fuel delivery system also incorporates various shut-off valves, pressure relief devices and sensors for fuel flow control and safety purposes.

- CNG fuel injection system (in place of or in addition to gasoline fuel injection system). Each OEM has pursued a somewhat different approach to CNG fuel injection design, some developing in-house technology and some acquiring technology from aftermarket gaseous fuel equipment manufacturers. The most advanced systems employ individual cylinder port injectors and computerized controls.

- Special materials are commonly used for engine valves and valve seats to protect against extra wear that may result from the lack of fuel lubricity.

- A special fuel tank pressure measuring system and dashboard display to indicate remaining CNG fuel supply (in place of or in addition to gasoline fuel gauge).

- Distinctive emblems identifying the vehicle as CNG fueled.

- Dedicated CNG models typically have a higher engine compression ratio to take advantage of the high octane rating of natural gas. The gasoline vapor emission control system may also be eliminated from a dedicated CNG vehicle.

2. Different Operational or Performance Features (from gasoline counterpart)

The most significant operating difference with CNG vehicles is the shorter refueling range and resultant need for more frequent refueling with natural gas. Most dedicated CNG models marketed to date, employing three or four fuel cylinders, carry the natural gas energy equivalent of 10 to 12 gallons of gasoline, allowing advertised refueling ranges of between 150 and 200 miles, or roughly one-half the range of gasoline counterparts. Ford made significant progress in this area with its 1997 CNG pickup truck, with a multicylinder system carrying the equivalent of over 20 gallons of gasoline and an advertised range of over 300 miles. Honda's CNG vehicle has an advertised range of 220 to 245 miles. Sometimes the full specified CNG vehicle cylinder capacity can only be partially realized, due to temperature and pressure conditions that prevent the fuel cylinders from being 100 percent filled and/or emptied. Typical bi-fuel vehicles retain their standard (15 to 34 gal.) gasoline tanks, and thus have a much-extended range with both CNG and gasoline.

CNG vehicle refueling procedure is similar to gasoline refueling procedure, except that the dispenser nozzle connection is an interlocking pressure fitting rather than the familiar gasoline nozzle. Quick-fill refueling facilities, such as those installed at about 90 public fueling stations in California to date, require approximately the same fill time as for a gasoline vehicle. Many fleets, however, operate their own slow-fill systems, where multiple vehicles are typically connected to the system overnight. Several companies have developed small-size commercial refueling appliances to supply one or two vehicles; however, the current market prices of these "home" systems remain high (in the thousands of dollars). The shorter refueling range and still relatively sparse public refueling network combine to restrict wide-ranging travel with dedicated natural gas vehicles, a primary reason for some manufacturers continuing to produce bi-fuel models.

Reduced horsepower and torque are characteristic of natural gas engines compared to otherwise identical gasoline engines, due to displacement of intake air by the gaseous fuel. For example, Chrysler reported a 13 percent reduction in horsepower in its 1992 model year 5.2 liter CNG engine, compared to the gasoline version of the same engine (both engines had 8.9:1 compression ratios). Ford indicates a 12 percent horsepower and torque decrease with its Crown Victoria 4.6 liter engine on CNG, as compared to the standard gasoline engine. Along with the increased weight of the fuel storage system, this results in a 1.7 second slower zero-to-sixty mph acceleration time (11.9 vs. 10.2 seconds). However, manufacturers have options to compensate for the inherent horsepower disadvantage of natural gas engines in order to meet specific horsepower objectives.

d. ***Maintenance and Reliability Features***

Available CNG models include the same warranty coverage as their gasoline counterparts, and service and repair functions are available at dealer service departments. While general claims of longer engine and engine component (e.g., spark plug) life have been made for natural gas vehicles, experience thus far with OEM CNG vehicles does not appear to provide a sufficient record to make any definitive comparison of long-term durability, nor to determine the frequency of CNG vehicle vs. gasoline vehicle repairs
) observing, for example, if any additional unscheduled maintenance incidence may be associated with unique CNG-related components. Increasing service intervals and longer component lives being experienced with new gasoline vehicles adds to the challenge of demonstrating a clear maintenance advantage for any new fuel technology.

With relatively small numbers of CNG vehicles sold thus far, service and repair may also be affected by lack of service department familiarity and limited stocking of replacement parts, especially for components supplied by aftermarket manufacturers. Another area where more in-use experience is needed for a more complete evaluation is the potential effects of variable natural gas fuel quality. Composition of pipeline natural gas is known to vary considerably, and the maintenance implications for current technology CNG vehicles of different concentrations of fuel impurities may not yet be fully established. Experience to date has shown some examples of vehicle maintenance problems, such as fuel injector malfunctions, that appear to be fuel quality related.

A problem encountered with fuel cylinder ruptures on a number of CNG vehicles in the U.S. has created considerable concern and widespread monitoring of CNG cylinder performance. At least six incidents of such tank failures have been reported, most resulting in substantial property damage, with some injuries also reported. GM's decision to suspend its CNG pickup truck offering was generally attributed to this problem. The seriousness of these incidents appears to confirm the need for continued rigorous attention to the design, construction, installation and maintenance of CNG vehicle fuel cylinders, and may affirm the continued need for periodic inspection and testing of such cylinders, a service procedure requiring removal of the cylinders from the vehicle at several-year intervals. GM's new CNG pickup for 1997 features improved fuel storage cylinder technology, employing carbon fiber-wrapped steel tanks meeting the latest industry standards.

e. ***Emission Features***

Natural gas vehicles from OEM companies have achieved the lowest emission certification levels of any combustion engine vehicles to date. Chrysler Corporation's 1993 CNG Dodge Ram Van/Wagon was the first vehicle to be certified by CARB as a Low Emission Vehicle. Chrysler also attained CARB emission certification for its second CNG model, the 1994 Plymouth Voyager/Dodge Caravan mini-van, at the ULEV level (O.04 NMOG), making this the first vehicle to certify as a ULEV. Ford has also certified its 1997 Crown Victoria and F-250 truck CNG models as ULEVs. Negligible fuel evaporative emissions (including running losses and refueling emissions) give dedicated CNG vehicles a further advantage over gasoline-fueled vehicles.

Honda recently released emission test results for the Civic GX CNG vehicle, scheduled for 1998 production, showing this vehicle to be the lowest-emitting combustion engine vehicle to date, with emission levels less than one-tenth CARB's ULEV standards.

GM's previous CNG pickup trucks also achieved CARB emission certification at levels well below prevailing standards, although not quite matching the extremely low exhaust levels of the Chrysler and Ford dedicated CNG vehicles which, due to their gasoline fueling capability, did not achieve the evaporative emission advantage. For the 1997 model year truck, GM and its upfitter, Impco Technologies, have achieved CARB

LEV certification status. Emission test results reported for converted CNG vehicles have been somewhat inconsistent, and have generally not matched the superior emission performance demonstrated to date by OEM CNG vehicles. However, these results may not be fully representative of vehicle conversions complying with California's recently implemented certification requirements applicable to such vehicles, which seek to assure that alternative fuel vehicle conversions result in emission benefits. Several converted CNG vehicles recently tested by CARB exhibited NMOG levels meeting the ULEV standard, as well as low NOx levels.

The low-emission potential of natural gas vehicles will be further enhanced by CARB's recent adoption of a reactivity adjustment factor for this fuel. For CNG vehicles meeting at least the LEV standards, tested NMOG levels will be effectively reduced by a RAF of 0.43 to reflect the lower level of ozone-forming reactivity determined for emissions from such vehicles. Natural gas appears to offer a greenhouse gas emission benefit over gasoline fueling, perhaps in the range of 20 percent less total carbon emissions on a total fuel cycle basis, although the technical debate about the greenhouse importance of methane emissions continues to affect this determination.

f. ***Fuel Efficiency Features***

Determination of the comparative fuel efficiency of natural gas vehicles and gasoline vehicles has been subject to considerable technical confusion, with natural gas variously reported as having inherently lower, higher or equivalent efficiency. Test results on this point remain inconclusive, with some data showing lower Btu/mile energy consumption with natural gas and other data showing higher energy consumption. Complicating such determination is the fact that CNG is a gaseous fuel, metered and sold on a different basis than gasoline which, along with variation in the Btu content of different natural gas supplies, may contribute to inconsistent energy equivalency measurements. Also, natural gas-fueled engines appear particularly susceptible to fuel economy compromises necessary to achieve low emission levels. On the other hand, recent test data from Ford on its Crown Victoria dedicated (ULEV certified) CNG vehicle indicates gasoline-equivalent city and highway fuel economy nearly identical to the gasoline counterpart.

CARB, for its purposes, has used an energy substitution factor for CNG vs. gasoline vehicles of 1.18 therms of natural gas to travel the same distance as on one gallon of gasoline. However, the basis for this factor, and whether it is consistent with actual CNG vehicle certification test results acquired by CARB to date, requires better documentation before it can be considered a firm assumption or used as an indicator of the relative efficiency of natural gas and gasoline vehicles. Others apply a factor of 1.1 therms per gallon.

g. ***Cost Features***

Higher initial acquisition prices prevail for current OEM CNG vehicle models, although the lower cost of natural gas compared with gasoline stands to at least partly offset the additional vehicle purchase cost. Chrysler, which initially priced its CNG Ram van $4,588 higher than the gasoline version, reduced the incremental price to $3,838 for the 1996 model year, or roughly 15 percent more for the CNG option. Ford's listed incremental prices for its 1997 CNG models range from $3,250 to $6,165; however, factory discounts substantially reduce the actual incremental purchase prices of most of these models to between $810 and $3,255.

GM's 1997 CNG pickup is listed at $5,800 above its gasoline counterpart. Future expanded production levels would be expected to reduce these incremental CNG vehicle costs, although the CNG fuel tanks, which comprise a major portion of the current cost differential, may continue to result in a cost premium for CNG vehicles. A major reason cited by Chrysler for suspending its CNG vehicle offerings was the high cost and limited availability of adequate fuel cylinders obtained from outside suppliers.

CNG fuel can currently be purchased at some public access stations in California at a gasoline equivalent price of about $0.90/gallon, a price that reflects significantly lower excise taxes on this fuel than on gasoline. At this price, representing about a 30 percent fuel cost advantage for CNG over gasoline, a fuel cost savings of 2.5 cents per mile would result from use of CNG. Thus, for some vehicles with high mileage operation, fuel cost savings could potentially offset the current incremental vehicle acquisition cost. For example, at a 2 cent per mile fuel cost saving, 30,000 miles per year of vehicle operation would result in a five-year payback (i.e., break even) on an initial price increment of $3,000. Fleet operators who install and operate their own on-site CNG fueling facilities and/or obtain a more favorable fuel price from a natural gas supplier, may be able to reduce this differential (although many large fleets similarly are able to reduce their costs of gasoline fueling). Of course, investment in CNG refueling facilities, which are more expensive than gasoline refueling facilities due to the required compressor, would add to the initial capital cost of establishing a CNG fleet.

Costs of maintaining OEM CNG vehicles are not documented well enough to attempt quantifying their impact on overall costs of owning and operating CNG versus gasoline vehicles. Potential savings in some areas of CNG vehicle maintenance costs (e.g., oil changes, certain engine components, etc.) may be possible, but other higher-cost areas may also result (e.g., costs of CNG cylinder inspection and testing). Until more detailed maintenance cost experience is acquired, and given the expected applicability of warranty coverage to most unscheduled maintenance events, non-fuel operating and maintenance costs of CNG vehicles can only be assumed to be the same as for gasoline vehicles.

h. *Challenges for Further Development*

Natural gas as a motor fuel alternative has made considerable gains in the last few years, due in large part to renewed interest and investment in this option by the natural gas utility industry, along with increasing CNG vehicle development activities by the automotive industry. Nevertheless, there are a number of remaining issues that affect the future extent of market penetration for this alternative, including:

- Vehicle Availability and Price

  Only a few OEM CNG light-duty vehicle models are currently available, and most of these models carry considerable incremental price premiums over their gasoline counterparts. The minimal model selection, especially among passenger car models, and the significant price increment, are limiting market sales levels.

- Refueling Infrastructure

  While a minimal network of about 90 public access CNG refueling stations, plus additional fleet facilities, have relatively quickly begun operation in the state, the extent of future expansion of this network, adequate to fully serve a growing CNG vehicle population, remains in question. This is primarily due to the high capital investment required for such facilities, their yet-to-be-determined profitability, and the uncertain plans of either the conventional (petroleum) fuel supply industry, the natural gas industry or others, to undertake a full-scale expansion.

- Natural Gas Industry Role

  Much of the recent progress with development and initial commercialization of the CNG vehicle option is directly attributable to natural gas industry supportive activities, funded from ratepayer revenues as authorized by governing bodies such as the California Public Utilities Commission. However, "ratebasing" of utility investments in natural gas vehicle technology and infrastructure development is now facing limitations that could restrict such investment in the future.

- Fuel Price and Taxation

  While natural gas currently enjoys a significant market price advantage over gasoline, the Commission's latest (Fuels Report '96) price forecast projects this advantage diminishing somewhat in the future. Furthermore, a major part of the current price advantage is due to lower state and federal taxes on natural gas. Any narrowing of the actual (untaxed) market price differential between natural gas and gasoline and/or addition of motor fuel taxes on natural gas more comparable to those on gasoline, methanol, LPG, etc. would erode the current market price advantage favoring natural gas.

- Vehicle Technology Issues

  Natural gas vehicle technology faces some continuing technical issues that, until and unless further progress is achieved, may serve to limit market acceptance. Foremost is the limited refueling range achievable with current technology dedicated CNG vehicles, typically about half that of gasoline counterparts. Safety concerns with high-pressure CNG technology appear reasonably well addressed, but some amount of renewed sensitivity accompanies cylinder failures on a number of vehicles, and safety may continue to require attention as a development issue. A related issue is the continuing high cost of these cylinders. Other remaining areas of technical concern with CNG vehicles include horsepower loss, and cargo capacity compromises due to fuel cylinder space and weight requirements. CNG vehicle emissions, while generally very favorable, will also require continued development emphasis to maintain a compelling advantage over improving gasoline vehicle emissions, which may also mean that any remaining bi-fuel emphasis will need to give way to dedicated vehicles exclusively.

C Fuel Quality Variations

The variability of the energy content and levels of impurities in natural gas present engineering obstacles for assuring optimal engine operating characteristics and vehicle reliability.

2. Heavy-Duty Vehicles

a. ***Industry Project Summary (see Table 8)***

Ten U.S. heavy-duty engine manufacturers, Caterpillar, Cummins, Deere, Detroit Diesel Corporation (DDC), Ford, Hercules, Mack, Navistar, Thermo Power, GM, and Volvo have thus far pursued heavy-duty natural gas engine development. Other U.S. manufacturers of heavy-duty trucks for the U.S. market, including Freightliner, Kenworth and Peterbilt are incorporating some of the above manufacturers' natural gas engines in their vehicles, as are bus manufacturers such as Blue Bird, Bus Industries of America, El Dorado National, and Gillig.

Several foreign manufacturers, including Isuzu, MAN, Mercedes-Benz, RABA and Volvo, are also engaged in heavy-duty natural gas vehicle/engine development.

Applications of natural gas by the above companies include transit buses, school buses, and various types of medium-duty and heavy-duty trucks, all dedicated natural gas vehicles. Both compressed natural gas (CNG) and liquefied natural gas (LNG) technologies are being applied.

In addition to the above OEM heavy-duty CNG engine/vehicle activities, some companies outside the OEM industry are engaged in development of systems for converting certain heavy-duty vehicle engines to CNG and/or LNG operation. A number of projects have also been undertaken by companies outside the industry involving "fumigated" natural gas/diesel technology. Some demonstrations of this approach have been conducted, but no conclusive technical results have been revealed to date that would point to compelling advantages or expected commercial offerings.

TABLE 8 NATURAL GAS HEAVY-DUTY ENGINE DEVELOPMENT BY OEM COMPANIES		
Engine	**Vehicle Applications**	**Status**
Caterpillar	E various trucks	E one engine model available; 2nd being demonstrated
Cummins	E trucks and buses	E three engine models available
Deere Power Systems	E school bus	E one engine model available
Detroit Diesel Corp.	E buses and trucks	E two engine models available; one more under development
Ford	E Ford F-600/F-700 truck	E 15 vehicle demo (complete)
Honda	E medium-duty trucks	E two engine models available
Isuzu (Japan)	E Isuzu 2-ton truck	E concept vehicle
Mack	E refuse truck	E prototype
MAN (Germany)	E buses	E engine available in Europe
Mercedes Benz (Germany)	E buses and trucks	E engine available in Europe
Navistar	E medium-duty trucks	E under development
Nissan (Japan)	E buses	E under development
RABA (Hungary)	E buses	E prototype engine
Thermo Power Corp.	E school buses, trucks	E two engine models available
Volvo (Sweden)	E truck	E ongoing demonstration

b. ***Commercial Availability Summary***

Five companies, Caterpillar, Cummins, Deere, DDC, and Thermo Power, offer commercially-available, CARB-certified heavy-duty natural gas engines in the U.S. The Cummins L10 engine is being used in CNG transit buses built by Orion Bus Industries for the Sacramento and Yolo Regional Transit Authorities. Thermo Power Corp. (formerly Tecogen) has supplied CNG engines for school buses built by Blue Bird Body Company (using GM chassis), 110 of which are being operated by school districts in California as part of the Commission's Safe School Bus Clean Fuel Efficiency Demonstration Program. Caterpillar made its first natural gas engine available for heavy-duty truck applications in 1995, and Deere began offering a natural gas bus engine in 1996.

Hercules previously supplied two different CNG heavy-duty engines, a four-cylinder and a six-cylinder. The six-cylinder version is being used in shuttle buses built by El Dorado National Corp. of Chino, California, some of which are in use by the Los Angeles Department of Transportation. Hercules is not continuing its CNG engine offerings at this time. Caterpillar is conducting a CNG engine demonstration project in a heavy-duty tractor/trailer truck, Mack Trucks is testing a prototype CNG engine in a refuse-hauling truck, and Ford has completed a 15-vehicle medium-duty CNG truck engine demonstration. Isuzu has built a 2-Ton LNG-fueled truck as a concept vehicle. DDC's 6V-92TA is being used in LNG buses at Houston Metro Transit. Converted heavy-duty natural gas vehicles (both CNG and LNG) are also in use in a number of applications.

c. ***Summary of Vehicle Technology Characteristics***

Heavy-duty vehicle applications of CNG, primarily in transit bus fleets such as that of Sacramento Regional Transit District, which has already accumulated millions of miles of CNG-fueled operation, are beginning to represent substantial in-use experience which, to date, appears to reveal satisfactory operation. As more documentation of these on-road fleets is compiled, including detailed comparisons of maintenance, reliability and fuel economy data for bus fleets employing CNG and diesel buses (and perhaps other alternative fuel technologies), a more definitive picture of overall operational performance will emerge. Applications of LNG have less in-use experience, and thus will require more time for extensive confirmation of technical characteristics.

Most of the technical features described above for light-duty CNG vehicles apply similarly to heavy-duty CNG vehicles, although the engineering designs of CNG fuel induction systems differ among the various engine manufacturers, particularly between engines adapted from diesel and gasoline operation. Also, the construction, size and placement of CNG storage cylinders varies among heavy-duty CNG vehicles and differs somewhat from typical light-duty applications. The extra storage space available on bus undercarriages allows use of larger and/or more numerous cylinders, affording current CNG bus models a somewhat longer refueling range (typically about 300 miles) than for light-duty CNG vehicles. In at least one bus design (that of Orion Bus Industries), the fuel cylinders are mounted in an enclosure installed on the roof of the vehicle.

LNG fueling requires use of lower pressure but highly insulated fuel storage vessels which maintain the necessary low temperature to store natural gas in the liquid state. LNG allows significantly greater energy storage density than CNG, providing longer driving range between refueling and/or requiring less on-board fuel storage capacity. However, current LNG storage vessels require some venting of fuel to relieve pressure build-up when vehicles are not operated for a period of time. For heavy-duty vehicles, which are typically used on a daily basis, and where refueling range and payload capacity are important considerations, LNG's higher energy storage density appears to offer a significant advantage over CNG.

Emission certification results to date for CNG bus models demonstrate this technology's ability to reduce emissions to levels well below prevailing CARB standards for hydrocarbons, carbon monoxide, oxides of nitrogen and particulate matter. Especially in the important particulate matter category, test results indicate that natural gas may offer the lowest levels measured to date, greatly improving over the levels achievable with particulate trap technology applied to diesel-fueled buses. Variability of natural gas fuel quality has presented a problem, both for emission calibration and vehicle operability, in some heavy-duty applications of natural gas vehicles.

The higher purchase cost of current CNG fueled heavy-duty vehicles (typically from $20,000 to $60,000 more than a diesel counterpart), combined with the cost of the required compressor and associated refueling equipment, make for a substantially higher initial investment cost for a CNG fleet versus conventional diesel vehicles. However, there is usually a fuel cost savings achievable with natural gas versus diesel fuel which, although not as great as the savings versus gasoline, should offset a portion of the higher prevailing capital costs of CNG technology. LNG fuel systems appear to involve even higher capital costs than for CNG systems, although some of this extra cost may be potentially offset by further fuel cost savings that may be achievable due to the capability for storing larger quantities of natural gas in liquefied form than in compressed form.

d. ***Challenges for Further Development***

Much of the earlier discussion regarding challenges for further development of light-duty natural gas vehicles is generally applicable to heavy-duty vehicle technology as well, with the following additional comments:

- Manufacturer activity on behalf of natural gas vehicles appears to be somewhat more widespread in the heavy-duty sector, perhaps because the low-emission advantage of natural gas over diesel is providing more of a stimulus. Nevertheless, expanded manufacturer involvement, and a broader array of vehicle options, will still be necessary for natural gas to become a major commercial option to diesel motor fuel.

- The natural gas price advantage over diesel fuel is even narrower than that over gasoline, and subject to the same future uncertainties with respect to taxation, etc. High price premiums for natural gas fueled heavy-duty vehicles present a difficult proposition for life-cycle cost recovery, even at the current comparative fuel prices.

- Where heavy-duty vehicle/engine manufacturers and/or heavy-duty vehicle fleet operators face difficult emission compliance requirements, natural gas appears to offer a promising emission control option, although continuing progress improving diesel vehicle emissions may be eroding the extent of benefits achievable with natural gas.

- Limited refueling range and lack of refueling facilities for natural gas present a particular challenge for heavy-duty vehicles that operate far from their home base, although locally operated fleets with their own on-site refueling facilities may not encounter this problem. LNG appears to be emerging as a favorable candidate for heavy-duty vehicles, since the additional fuel storage capacity achievable with LNG (vs. CNG) allows for significantly longer refueling range.

D. LIQUEFIED PETROLEUM GAS

1. Light-Duty Vehicles

a. *Industry Project Summary (see Table 9)*

GM, Ford and Chrysler have all been engaged in LPG light-duty vehicle development programs, Ford's LPG efforts dating back to the early 1980s. Current vehicle applications of LPG being pursued by the "big three" include various sizes of pick-up trucks and vans.

Outside North America, LPG vehicles are being produced by several Japanese companies, including Mazda, Nissan and Toyota, and by GM's Australian subsidiary, Holden Motors, as well as Ford's Australian division. Renault in France and Fiat in Italy are also pursuing LPG vehicle development. Development of LPG vehicle fuel system components is also taking place outside the OEM auto industry. Various companies produce individual components and kits for both LPG vehicle conversions and OEM applications, with some of these companies actively involved in their own development of advanced technologies, including vehicle testing and demonstration programs.

b. *Commercial Availability Summary*

Ford has disclosed plans to produce its F-150/F-250 pick-ups with a bi-fuel LPG/gasoline option beginning in late 1997 as 1998 models. This vehicle has previously been offered on a limited basis as an upfitted vehicle through Ford's "Qualified Vehicle Modifier" program. Ford also offered a production LPG option in the U.S. on its Granada model during the mid-1980s, and more recently has offered a "propane prepared" engine option in U.S. light-duty van and pick-up truck models, beginning with the 1993 model year.

TABLE 9
LPG LIGHT-DUTY VEHICLE DEVELOPMENT PROJECTS BY
OEM AUTO COMPANIES

Company	Model	Status
Chrysler (Canada)	E Dodge Ram Van/Wagon	E available in Canada
Fiat	E Tempura	E development
Ford	E F-150/250 Pickup E Pickups and vans E Granada	E announced as market option for 1998 model year E available with LPG prepared engine E offered 1982-85
Ford (Australia)	E Falcon	E currently offered in Australia
GM	E Pick ups and vans	E available w/ LPG prepared engine
GM/Holden (Australia)	E Various	E currently offered in Australia
Mazda	E Small truck	E available in Japan
Nissan	E Laurel, Cedric, Bluebird	E models currently offered in Japan
Renault	E Ludo	E concept vehicle
Toyota	E Mark II, Corona, truck	E models currently offered in Japan

This option includes internal engine components (valves, etc.) engineered to accommodate LPG fueling, but requires the entire LPG fuel system to be installed following delivery. GM began a siar "propane prepared" truck and van engine option in the same model year. Chrysler Canmilada has introduced a dedicated LPG version of the Dodge Ram Van/Wagon in the Canadian market for the 1997 model year. GM's and Ford's Australian divisions currently offer LPG passenger car models for sale in that country, and Mazda, Nissan and Toyota all offer LPG passenger car and/or small truck models in Japan.

Most of the world's existing population of LPG vehicles (estimated in the several-million range) are converted vehicles, including the estimated 30,000 LPG vehicles in California operated mainly by commercial fleets. Conversions of gasoline vehicles to LPG operation have been available for many years, with continuing efforts by conversion equipment suppliers to keep pace with advancing OEM vehicle technologies. Companies that have most recently offered CARB-certified equipment for LPG vehicle conversions in California are listed in Table 9A. New, more stringent CARB regulations governing the certification of LPG vehicle conversion systems are being implemented, with the continued marketing of systems for new vehicles by the various suppliers still somewhat uncertain. No conversions of 1996 or 1997 model year vehicles have thus far been certified under these new regulations.

TABLE 9A CARB-CERTIFIED SUPPLIERS OF LPG VEHICLE CONVERSION SYSTEMS (for 1994 & later model year light-duty vehicles, as of Aug. 1997)
GFI Control Systems, Inc., Ontario, Canada (for 2 GM & 1 Ford 1995 engine families)
Impco Technologies, Inc., Cerritos, CA (for 4 GM & 3 Ford 1994 engine families)
OHG Inc., Los Angeles, CA (for 1 GM & 1 Chrysler 1994 engine family; 3 GM 1995 engine families)

3. *Summary of Vehicle Technology Characteristics*

The previous examples of LPG light-duty vehicle models offered by OEM companies in the U.S. and Canadian markets allow for characterization of this technology. LPG is dispensed and stored as a liquid under moderate pressure (several hundred pounds per square inch). Most vehicle storage tanks in use are heavy gauge steel cylinders manufactured by specialty aftermarket companies. Another group of suppliers produce most of the gaseous fuel vehicle fuel induction system components in use, which include pressure regulating converters for bringing the fuel from a liquid to a gaseous state, special carburetion or fuel injection units for delivering the proper gaseous fuel/air mixture for engine combustion, refueling connectors, fuel lines, safety valves and other hardware components. Chrysler Canada has developed its own sequential multi-point propane fuel injection system for its vehicles.

Dedicated LPG vehicles may incorporate higher engine compression ratios to take advantage of the fuel's high octane; however, this is rare with vehicle conversions due to the extra expense. Engines produced for propane use by OEM companies, including the "propane-prepared" engines currently offered in some gasoline vehicle models, typically include special valve train components designed for durability under LPG fueling conditions. Many LPG vehicles are bi-fueled (also referred to as dual-fueled), retaining their original gasoline tanks and fuel systems with the capability for switching between gasoline and LPG operation.

LPG contains approximately 75 percent as much energy per gallon as gasoline, with driving range per gallon likely to be reduced proportionately, although some LPG fleet operators have reported LPG fuel economy closer to that of gasoline. Efficiency testing of LPG vehicles versus gasoline counterparts has thus far not provided conclusive results to determine whether improved efficiency of LPG engines can indeed compensate for a portion of the fuel's lower energy content. A moderate loss of engine power output has also been commonly considered characteristic of LPG vehicle conversions; however, some LPG fleet operators have indicated this to be a minor factor. As with natural gas vehicles, OEM LPG vehicle engineering can likely incorporate compensating features to match horsepower output of gasoline engine options.

Emission testing of LPG vehicles has also been limited, especially for OEM vehicles with engines designed and calibrated specifically for this fuel. Emission testing of converted LPG vehicles has produced somewhat mixed results, in some cases showing substantial improvements over gasoline and in other cases showing worse results. However, it appears that with adequate vehicle engineering, LPG offers significant potential emission advantages over gasoline, although specific emphasis on low emission LPG vehicle technology development lags somewhat behind other alternative fuels. Recent testing by CARB of seven converted LPG vehicles showed all to have NMOG exhaust emissions below the TLEV standard, with some close to the LEV standard, and all showing low NOx levels as well. With CARB's recent adoption of a reactivity adjustment factor for LPG, vehicles testing at LEV levels or below will have NMOG adjusted to 50 per cent of the tested level to reflect the lower ozone-forming reactivity of emissions from this fuel. Some LPG vehicles tested by CARB have met LEV/ULEV standards, with ozone-forming potential almost as low as natural gas vehicles.

Greenhouse gas emissions from LPG vehicles have also not been as thoroughly evaluated as for other fuels; however, it appears that overall carbon emissions from the entire LPG fuel cycle are somewhat less (perhaps by about 20 percent or more) than from the gasoline fuel cycle.

LPG is often reported to offer extended engine and component life, sometimes expressed in terms of reduced maintenance requirements, with various LPG-using fleets providing testimonials to this effect. Nevertheless, definitive evidence to support or quantify the extent of such an advantage remains incomplete, particularly as a direct comparison with the latest gasoline vehicle maintenance characteristics, which continue to improve.

The relative cost of fuel continues to favor LPG over gasoline, although the margin of difference appears to have narrowed somewhat from past years. LPG prices at many retail outlets catering mainly to small-scale non-motor fuel markets (e.g., fuel for recreational vehicle appliances, home barbecues, etc.) are actually higher than gasoline prices on a per-gallon basis, providing a somewhat misleading indication. Wholesale LPG market prices are more indicative of the prevailing LPG/gasoline price relationship, with LPG enjoying a 10-20 percent advantage on an energy equivalent basis. A limited network of LPG industry-established outlets serving the motor vehicle market, typically card-lock accessed facilities serving fleet customers, offers fuel at prices competitive with gasoline. Fleet operators with their own on-site LPG fueling facilities can usually obtain fuel at more favorable prices, sometimes reflecting the above wholesale price advantage over gasoline in large bulk quantity purchases. Even so, at current low gasoline prices, realizing a 20 percent fuel savings over gasoline) amounting to about a 1 to 2 cents per mile savings in vehicle operating cost) may be about the best case achievable with LPG fleet fueling. The incremental price of Ford's upcoming 1998 bi-fuel pickups is not yet announced; however, the 1996 "QVM" LPG pickup truck was priced at $2,800 above the gasoline version (with factory discount).

d. ***Challenges for Further Development***

Measured by the total number of alternative fuel vehicles in use in California, the U.S. and the world today, LPG has achieved the greatest market penetration of any alternative motor fuel. However, the current LPG vehicle population in the state is believed to be lower than in past years, and continuing to decline. A number of factors are responsible for the instability and uncertain growth prospects for vehicular use of LPG, including:

- Vehicle Availability

  Current and prospective LPG fleet operators face continuing difficulty obtaining an adequate selection and supply of LPG vehicles, due to limited OEM options and new CARB certification requirements for vehicle conversions.

- Fuel Status and Supply Outlook

  Debate continues over whether LPG is truly an "alternative fuel" (since some of its sources are petroleum-based). While the federal government (in EPACT) has officially designated LPG as an alternative fuel, California remains less positive. Despite industry-sponsored analyses that indicate a favorable outlook for LPG supplies adequate to support a substantially expanded motor fuel market, questions remain (from within and outside the industry) as to the extent of a potential supply constraint on the further development of LPG as an alternative fuel.

- Retail Fuel Price Variability

  While LPG has maintained a wholesale price advantage over gasoline for many years, retail pricing at locations accessible for vehicle fueling varies widely, and at many locations, LPG is priced higher than gasoline. This tends to make LPG's price competitiveness with gasoline unclear, and even discourages potential users due to a perception of high prices. Seasonal price fluctuations, influenced by weather and other factors associated with non-motor fuel markets, have also been experienced.

- Fuel Quality Restrictions

  Pending CARB regulations will place new, more severe restrictions on the composition of LPG that can be sold as motor fuel in the state, providing less flexibility in the sources and types of LPG that can be marketed for vehicle use, and possibly requiring separation of motor fuel LPG from that distributed for other end uses.

- C Low Emission Vehicle Status

  While the low emission potential of LPG is becoming better confirmed in general, examples of vehicle technology that take full advantage of this potential and achieve certified emission levels that meet California's LEV and ULEV standards are still not being demonstrated.

- C Vehicle Technology Advancement

  LPG has received less technology development support from OEM auto companies, government and other entities than some other alternative fuels, placing it somewhat behind these other vehicle fuel options with respect to technology advancement and optimization.

- C Dispersed Industry Base

  Much of the LPG supply industry consists of small independent companies, and a concerted industry base of support for expanding the motor fuel application of LPG has not thus far been established.

2. Heavy-Duty Vehicles

a. *OEM Project Summary (see Table 10)*

Ford and Caterpillar have developed LPG-fueled engines for use in various truck applications, and Cummins and DDC also have heavy-duty LPG engines under development. A California bus manufacturer, El Dorado National Corp, is developing an LPG transit bus model under contract to Orange County Transit, a long-time user of LPG. Outside the U.S., Mercedes-Benz and MAN in Germany, Sisu Auto and Valmet in Finland, and DAF in the Netherlands, are known to be engaged in heavy-duty LPG vehicle projects.

b. *Commercial Availability Summary*

Caterpillar commercially offers an LPG version of its model 3306 (250 hp) engine. A Canadian truck manufacturer, Western Star Trucks, has begun using this engine in its line of LPG delivery trucks. Ford reintroduced (dedicated) LPG as an option for its F-600 and F-700 trucks in the 1994 model year, after discontinuing for several years its previous offerings of LPG trucks, many of which were sold in the U.S. and California in past years. After the 1996 model year, however, Ford discontinued this truck series, and has yet to announce a replacement LPG truck model offering. Mercedes-Benz reportedly offers its LPG truck engine in the Brazilian truck market, and MAN, Sisu Auto, Valmet and DAF are all reportedly supplying heavy-duty LPG vehicles for European demonstrations. A Texas company, Vinyard Engine Systems, offers converted Cummins and Navistar engines for LPG use.

TABLE 10
LPG HEAVY-DUTY ENGINE DEVELOPMENT
BY OEM COMPANIES

Engine	Vehicle Application	Status
Caterpillar	E trucks, transit buses	E one engine model available; one under development
Cummins	E transit buses	E two engine models under development
DDC	E buses, trucks	E transit bus demonstration
DAF (Netherlands)	E transit buses	E available in Europe
Ford	E Ford F600 & F700 trucks	E market offering through 1996
MAN (Germany)	E transit bus	E available in Europe
Mercedes Benz (Germany)	E M-B truck	E supplied to Brazil
Sisu (Finland)	E Sisu truck	E currently available in Sweden
Valmet (Finland)	E bus	E demo in Europe

c. ***Summary of Vehicle Technology Characteristics***

Ford's F700 truck, with a gross vehicle weight rating of 37,600 pounds, available in recent model years, provides one example of OEM LPG truck technology. This truck has been produced in cab-and-chassis configuration and then outfitted following sale for a wide variety of uses, ranging from delivery to construction to agricultural applications. One popular fleet application of this vehicle with the LPG option has been by LPG suppliers, who outfit the truck with an LPG "bobtail" tank for fuel delivery service.

The F600/700 truck has a standard 7 liter, carbureted engine which, for the LPG option, has been factory equipped for LPG operation using fuel system components (LPG converter, vacuum filter fuel lock and air-valve carburetor) manufactured by Impco Inc. of Cerritos, California. The LPG system operates at a tank storage pressure of about 200 psi, with the (liquid) fuel from the tank vaporized to atmospheric pressure by the converter prior to engine carburetion. The LPG engine option has essentially the same horsepower rating as the standard gasoline version (approximately 216 hp), although higher output options on gasoline have been produced. Ford has delivered this vehicle with only a temporary seven-gallon LPG fuel tank, with the installation of a permanent fuel tank or tanks necessary after sale. Warranty coverage has been identical for LPG and gasoline models.

CARB emission certification results for the Ford F600/700 LPG truck show a significant emission improvement for the LPG model compared to its gasoline counterpart. Total hydrocarbons for the LPG vehicle measured less than one-half the gasoline vehicle level. Ford's LPG truck also achieved oxides of nitrogen emission certification results about 36 percent lower than the same vehicle on gasoline.

The F600/700 LPG option has listed for an additional $1,042 above the base gasoline vehicle price (typically $25,000 to $30,000 for the cab and chassis). A typical two-tank installation of steel LPG cylinders has typically cost an additional $1,000. Thus, if an LPG vehicle fleet operator realizes a 20 percent annual fuel cost savings with LPG over gasoline, a payback could perhaps be achieved on the initial vehicle (and tank) cost differential within about four years, or less in high-mileage (i.e., 20,000 miles per year or more) applications.

d. *Challenges for Further Development*

The previous discussion of challenges for further development of light-duty LPG vehicles applies to heavy-duty applications as well.

E. HYDROGEN

1. Light-Duty and Heavy-Duty Vehicles

a. *OEM Project Summary (see Table 11)*

German companies Mercedes-Benz, BMW and MAN, the Japanese auto maker, Mazda, and the South Korean company, Hyundai have undertaken development of hydrogen (combustion engine) vehicle technology. Light-duty applications have included various sizes of passenger cars (including station wagons) and delivery vans. Heavy-duty hydrogen transit buses are also under development by Mercedes-Benz and MAN. A Canadian bus manufacturer, Novabus, is testing a bus on "Hythane," a mixture of 20 percent hydrogen and 80 percent natural gas. In addition to the above OEM projects, a number of hydrogen vehicle technology development projects have been pursued outside the automotive industry, including a major ongoing program at the University of California Riverside Center for Environmental Research and Technology.

Another potential transportation energy application for hydrogen is as the fuel source for fuel cells, which are under development for use in hybrid electric vehicles (see further discussion in the following section).

b. ***Commercial Availability Summary***

No hydrogen vehicle model has yet been introduced in the international automotive marketplace. The most extensive on-road demonstration of hydrogen vehicles to date has been conducted in Germany by Mercedes-Benz. This company, which has been working on hydrogen-fueled engine technology since 1973, conducted a four-year fleet demonstration of ten hydrogen vehicles) five 280TE model station wagons and five 310 model vans) in Berlin from 1984 to 1988, accumulating about half a million miles of operation. The vans were dedicated gaseous hydrogen vehicles, while the station wagons employed a combination fuel system that allowed use of hydrogen/gasoline mixtures. Mercedes-Benz has demonstrated other individual hydrogen vehicle models as well, including a 230E model hydrogen research vehicle shown in Washington, D.C. in 1989. BMW's hydrogen vehicle development activities began in about 1980, concentrating on liquid hydrogen fueling and resulting in operation of at least three experimental vehicles, including a 520 model and two 735i models.

Mazda has conducted hydrogen engine research with both conventional piston engines and with its rotary engines, testing and exhibiting several hydrogen vehicles, including an experimental hydrogen-fueled, rotary engine-powered Miata. Mazda has discussed a possible U.S. hydrogen vehicle demonstration program, but no definite plans have been announced. Hyundai has reported on its hydrogen engine vehicle testing activities, but has not yet publicly exhibited a hydrogen vehicle. MAN and Mercedes Benz have each developed a hydrogen fueled transit bus for a demonstration taking place in Germany.

TABLE 11
HYDROGEN VEHICLE DEVELOPMENT BY OEM COMPANIES

Company	Vehicle	Status
BMW	E 520, 735i	E experimental liquid H2 E vehicles operated
Hyundai	E HV	E engine/vehicle testing
Mazda	E HR-X2 E MX-5	E concept vehicle E concept vehicle
Mercedes Benz	E 280TE, 310 van E 230E E transit bus	E 10 vehicle demo (complete) E concept vehicle E demonstration in Germany
MAN	E transit bus	E demonstration in Germany
Novabus	E transit bus	E "Hythane" bus being tested

c. ***Summary of Vehicle Technology Characteristics***

The above OEM projects have successfully demonstrated the adaptability of conventional internal combustion automotive engines to hydrogen fueling. Hydrogen vehicle technology has been able to apply some of the same gaseous fuel system and fuel storage technology advances being developed for CNG and LNG vehicles. Several previous significant concerns regarding hydrogen's internal combustion engine adaptability, including safety, fuel mixture pre-ignition and backfire, and engine power loss, appear to have been largely resolved in the above vehicle demonstrations, although, as with other gaseous fuel technologies, compensating for power loss is necessary to maintain gasoline engine power output. Mazda's rotary engine technology looked to have certain features effective for overcoming unsatisfactory engine operating conditions and resulting vehicle driveability problems commonly associated with hydrogen combustion, but Mazda's reconsideration of its overall rotary engine program leaves the future of this concept in doubt. Advanced fuel injection system designs adapted to hydrogen have also been effective at overcoming engine operational problems in conventional piston engines. Long-standing concerns regarding the safety of hydrogen (sometimes referred to as the "Hindenberg syndrome") appear to have little actual foundation as applied to automotive application of this fuel, based on the demonstrated operation of hydrogen vehicles to date.

Limited emission testing of hydrogen vehicles confirms the potential for achieving the lowest emissions levels of any combustion engine/fuel technology. Nevertheless, despite occasional references to "only water vapor" being emitted from hydrogen engines, there are emissions that require controls) primarily NOx, and possibly traces of hydrocarbons from engine oil consumption. Recent hydrogen vehicle emission testing by Hyundai showed NMOG emissions at only about one-third and NOx at about one-fifth ULEV levels from a catalyst-equipped hydrogen-fueled engine. Mazda has also indicated its belief that it could establish low enough emission levels from its rotary engine hydrogen vehicles to qualify for consideration as "zero emission vehicles" under CARB's ZEV standard. This possibility is made more realistic by CARB's pending consideration of an "Equivalent ZEV level" that would quantify the level of power plant emissions resulting from recharging the battery of an electric vehicle and allow other vehicle technologies meeting this low emission level to be considered ZEVs, although EVs are currently considered the only ZEV option. Still, it remains to be demonstrated that hydrogen vehicles could achieve and maintain low enough emission levels, especially for NOx, to qualify as an EZEV.

Aside from the small amount of emissions from engine oil consumption, hydrogen-fueled vehicles would not directly emit (fuel-based) carbon emissions. If natural gas remains the feedstock however, the entire hydrogen fuel cycle could contribute total carbon emissions comparable to other natural gas-based fuel cycles. On the other hand, if solar energy or another renewable form of energy is used to produce hydrogen from water, total carbon emissions from hydrogen fuel use could be negligible.

The major remaining technical issue for hydrogen-fueled vehicles is on-board energy storage capacity. Hydrogen gas, even when compressed to the high pressures (e.g., 4,000 psi) allowed by current gaseous fuel storage cylinder technology (as previously described for natural gas), has only 1/10 or less the energy density of an equal volume of gasoline. Thus, a vehicle running on compressed hydrogen gas would require at least ten times as much on-board fuel storage volume to achieve the same refueling range as a gasoline vehicle. Or, with triple the fuel storage volume of a gasoline vehicle, the hydrogen vehicle would have only one-third or less of the gasoline vehicle's refueling range. With the advent of "metal hydride" storage media, used by both Mercedes-Benz and Mazda, more hydrogen can be stored within the same space with the same pressure, allowing about a doubling of energy storage density of conventional compressed hydrogen tanks, but still representing only about 20 percent of the range of a gasoline vehicle. Liquefied hydrogen storage, such as employed by BMW, requires the use of double-wall, vacuum super-insulated tank technology to maintain the low liquid temperature (-273 deg C), allowing somewhat greater energy storage density than metal hydride storage, but still only about one-fourth of gasoline's storage density.

The current high cost and low availability of hydrogen for use as motor fuel impose further limitations on its potential application. Except for aerospace uses, hydrogen is supplied today mainly as an industrial gas produced from natural gas, and its current market price reflects this limited usage by non-energy markets, even though its estimated production cost from natural gas is in the same range as the cost of producing gasoline, on an equivalent energy basis. However, more advanced hydrogen production concepts involving water electrolysis, and often applying renewable forms of production process energy, have much higher projected costs, with the most favorable estimates at several times current gasoline cost.

d. ***Challenges for Further Development***

Hydrogen has been successfully demonstrated on a limited basis as a motor vehicle fuel. Before hydrogen can achieve commercial status as an alternative transportation fuel, however, substantial further development progress in the following areas will be necessary:

- Fuel Cost

  While conventional hydrogen production (from natural gas) could potentially achieve competitive economics with petroleum fuels, there is little current incentive to pursue this objective. What support exists for hydrogen as a fuel option results mainly from its potential renewability and environmental benefits if produced from water electrolytically, using solar energy or other non-fossil energy forms. This, in turn, places hydrogen cost estimates in a range several times the current cost of petroleum fuels.

- Storage Capacity

  Current hydrogen storage systems for motor vehicles provide only a fraction of the refueling range of gasoline vehicles.

- C Vehicle Operational and Safety Issues

  While the limited (mostly foreign) field trials to date with hydrogen fuel vehicles appear to have shown the ability to overcome the technical issues and safety concerns that previously surrounded use of this fuel, much more extensive real-world demonstration experience (including in the U.S.) will be necessary to adequately prove the acceptability of hydrogen for widespread on-road use.

- C Lack of Sustained and Coordinated Development Efforts

  Individual efforts to apply hydrogen for motor vehicle fueling have taken place for many years by organizations in the U.S., Germany, Japan and other countries. Due to their modest individual resources and lack of any systematic, concerted continuous approach, however, the collective progress of these activities has been limited.

F. ELECTRIC AND HYBRID ELECTRIC VEHICLES

1. Light-Duty Vehicles

a. *Industry Project Summary (see Table 12)*

Development of light-duty highway vehicles with electric propulsion is being pursued by the big three U.S. auto makers and by most of the major Japanese and European OEM companies. Over 80 different electric vehicle (EV) development models have been reported as resulting from projects by 25 different OEM companies. California's ZEV standard is considered to be a major impetus for this proliferation of auto industry EV activity. Original provisions of this regulation that would have required a fraction of California vehicle sales to be EVs beginning in 1998 have been replaced with an agreement between the California Air Resources Board (CARB) and the major auto companies to conduct expanded EV demonstration programs until the year 2003, when the regulation takes effect with a requirement for 10 percent of light-duty vehicle sales in California to be ZEVs.

Most EV development models to date have been battery-operated vehicles, which obtain all of their energy via battery charging from the electricity supply "grid." Recently, there has been an increasing emphasis on "series" hybrid technology approaches, wherein part or all of the electricity is produced on-board the vehicle. Most series hybrid EVs employ one of several configurations of combustion engine/generator as their on-board "auxiliary power unit." The "parallel" hybrid technology concepts use both electric propulsion and conventional internal combustion (IC) engine propulsion in combination. More advanced technology in the form of electricity-producing fuel cells, electrochemical devices that produce electricity directly from hydrogen and oxygen, is undergoing initial experimental application as the on-board electricity source in a few hybrid EV projects within and outside the mainstream automotive industry. Flywheel energy storage is also undergoing initial EV research application as a potential supplement to, or substitute for, the various electric storage battery technologies under active development.

GM has pursued various EV development projects since the 1960s, and in 1990, unveiled a two-passenger sports coupe electric automobile, the Impact, which has completed a major demonstration program. A current generation version known as the EV1 began limited commercial introduction in late 1996, followed by an electric pickup truck model from GM. Chrysler has also conducted a multi-year EV development program concentrating on passenger/cargo vans, and Ford has been pursuing EV development based on compact truck models. European companies BMW, Volkswagen, Audi, Opel, Mercedes-Benz, Volvo, Peugeot, Renault and Fiat, and Asian companies Nissan, Toyota, Honda, Mazda, Mitsubishi, Subaru, Suzuki, Daewoo, Daihatsu, Kia, Samsung, Ssangyong and Hyundai have all undertaken compact EV passenger car and/or van development.

OEMs with hybrid electric vehicle development projects, most involving compact passenger cars or vans, include GM, Ford and Chrysler, Audi, Opel, BMW, Mercedes-Benz, VW, Peugeot, Volvo, Mitsubishi and Mazda. Chrysler, Ford, and GM have all experimented with flywheel energy storage as part of their hybrid EV development projects. Mercedes-Benz' parent company, Daimler-Benz, has developed two versions of an experimental fuel cell EV van. Toyota has also revealed a fuel cell vehicle project, and Ford and Chrysler both recently announced plans for fuel cell vehicle development.

Outside the recognized OEM auto industry, several American and European specialty vehicle manufacturers have developed ground-up EVs (as distinguished from an even larger number of companies who convert gasoline vehicles to EVs), some of which may be viable potential market candidates. A consortium of California companies and public agencies (CALSTART) has been formed with the objective of establishing a viable production capability for EVs and/or EV components in California, thus far leading to the construction of a prototype electric passenger car model by specialty automotive companies in the state under CALSTART's auspices. At least two companies, Cushman Industries and Doran, have developed two- or three-wheeled EV cycles for the meter-reader or motor scooter markets. Two other U.S. companies, Grumman and Taylor-Dunn, are entering the market as producers of on-road special-purpose electric delivery vehicles.

b. ***Commercial Availability Summary***

Chrysler built about 50 TE Vans, an electric version of the Caravan/Voyager minivan in 1993-95, primarily for use in electric utility fleets. In December 1996, GM began leasing the EV1 at 25 Saturn dealerships in California and Arizona. As of early 1997, about 200 EV1s had reportedly been leased. Additional public offerings of EVs in the U.S. for 1997 are Ford's Ranger pickup, GM's S-10 pickup and Honda's EV Plus. Chrysler's EPIC van and Toyota's RAV4 sport utility vehicle are scheduled as 1998 models. Ford has also made the Ranger EV available through its "Qualified Vehicle Modifier" program. Limited market availability of electric vehicles from the OEM auto industry also appears to have begun in Japan and Europe, based on reported limited public offerings of EV models by Nissan, Toyota, Daihatsu, Renault, Peugeot and Mercedes Benz.

Only about 800 EVs are estimated to be in operation in California today, including many converted gasoline vehicles, some prepared as "do-it-yourself" projects by EV enthusiasts and some prepared by one of several commercial EV conversion companies. Several models of limited production electric vehicles from small European specialty manufacturers are also available and have been purchased in small numbers, primarily by utility companies. Examples include the Danish-built City-El and Kewet

El-Jet, and Norwegian-built AVCO station cars, one or two-passenger commuter vehicles, sometimes called "neighborhood Evs."

TABLE 12

ELECTRIC LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM AUTO COMPANIES

Company	Model	Status
Adam Opel AG	E Opel Twin Van (hybrid)	E design stage (1992)
Audi AG	E Duo (hybrid)	E design stage (1992)
BMW	E E1, E2, E 735iL (hybrid) E 320	E concept (1992-93) E concept (1990) E 10 vehicle demo(1990)
Chrysler	E TE Van E Epic Van E Patriot (hybrid) E Intrepid ESX (hybrid) E LHX (hybrid-fuel cell)	E 50 built (1993-95) E available for 1998 E concept (1994) E concept (1996) E development
Daewoo	E DEV-2, DACC-II, Green	E concepts (1995)
Daihatsu	E Micro Van, pickup E Hybrid Sedan E P-100	E available in Japan E concept (1993) E concept (1996)

TABLE 12

ELECTRIC LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM AUTO COMPANIES

Company	Model	Status
Fiat	E Elettras E Downtown E Ducato Van E Zic	E available in Italy E concept (1993) E planning E prototype (1995)
Ford	E Synergy 2010 E Ecostar truck E ETX-II (1989) E EVent E Ranger pickup	E concept vehicle E 100 vehicle demo E concept vehicle E concept vehicle E available (1997
GM	E Impact E EV1 E S-10 Pickup E Lumina (hybrid) E HX3 Van (hybrid) E Geo Storm E Griffon Van	E demo (1994-96) E limited intro (1996-97) E available (1997) E concept (1995) E concept E concept E demo (1985)
Honda	E CUV-4 E EVX E EV Plus	E prototype (1995) E concept (1993) E limited intro(1997)
Hyundai	E FGV-1 E Accent	E concept (1995) E prototype (1997)
Kia	E KEV-4, Pride	E concepts (1994-95)
Mazda	E HR-X (hybrid) E Miata E Roadster	E concept (1991) E demo (1993) E concept (1995)
Mercedes Benz	E 190E & MB 100 E Necar I&II (hybrid) E Sprinter Van E Smart	E demo (1994) E concept (1994-96) E available in Germany E concept (1994)
Mitsubishi	E ESR E Expo E HEV (hybrid)	E concept (1993) E prototype (1995) E prototype (1995)

TABLE 12

ELECTRIC LIGHT-DUTY VEHICLE DEVELOPMENT BY OEM AUTO COMPANIES

Company	Model	Status
Nissan	E Cedric/Gloria E FEV I&II E Micra E Sun Favor E Avenir E Prairie Joy E EV E HEV (hybrid)	E available in Japan E concept (1992-95) E concept (1989) E concept E available in Japan E available in Japan E development for 1998 intro E development
Peugeot/Citroen	E AX-106 E J5 Van E C-15 Van E 205 Sedan E Citela, Tulip, Ion E Saxo Electrique	E available in France E demo (1990) E demo (1991) E demo (1990) E concepts (1992-95) E prototype
Renault	E Express E Clio E Next	E demo (1994) E available in France E prototype
Samsung	E SEV-III, SEV-IV	E prototype (1994-96)
Ssangyong	E CCR-1	E concept (1995)
Subaru	E Elcapa	E concept (1995)
Suzuki	E EE-10	E concept (1993)
Toyota	E Crown Majesta E Town Ace Van E EV-50 E Prius E RAV 4 E FCEV	E concept (1993) E demo (1990) E concept (1993) E concept (1995) E available in Japan E concept (1995)
Volkswagen	E Chico (hybrid) E Golf (hybrid) E Jetta (1991) E Concept 1	E prototype (1995) E demo (1992) E demo (1991) E concept (1994)
Volvo	E ECC (hybrid) E 850	E concept (1992) E concept (1995)

Hybrid EVs, including vehicles incorporating fuel cells and flywheels, are in the research and experimental stage. The first light-duty fuel cell EV to be shown publicly by an OEM company was the Mercedes-Benz "Necar," unveiled in 1994, a second generation version of which is now being tested in Europe. This vehicle incorporates a proton exchange membrane (PEM) fuel cell developed by Ballard Power Systems of Canada, a leader in the development of fuel cell technology for vehicular applications. Toyota displayed a fuel cell concept vehicle in Japan in 1996, featuring a new hydrogen fuel storage technology developed by the company. Chrysler recently announced plans for a fuel cell vehicle project, intended to employ gasoline as the on-board fuel source supplying the fuel cell, and Ford is undertaking a fuel cell vehicle development program with the U.S. Department of Energy.

c. ***Summary of Vehicle Technology Characteristics***

1. Unique Technical Features

Most light-duty electric automobile and van models demonstrated by OEMs to date (and supplied as conversions) are battery operated and utilize alternating current (AC) or direct current (DC), variable-speed electric motor propulsion systems, employing advanced, compact electric motor technology developed in-house or by specialty manufacturers. AC technology is being employed by GM, Chrysler, and Ford, while Honda, Toyota, and Nissan are using DC systems. Electric motors replacing the conventional IC engine may utilize a single speed central drivetrain system or be positioned to drive individual wheels. On most EVs, the underhood space normally occupied by the IC engine houses the electric motor controller system and associated electronics.

An interconnected series of storage batteries comprises the most unique and substantial component of most EVs, typically more than replacing the weight of an IC engine and fuel system and resulting in a net weight addition of from several hundred to over 1,200 pounds compared with a similar size gasoline vehicle. In some traditional battery-electric vehicle configurations, a portion of the vehicle's normal cargo space is occupied by batteries numbering as few as 6 to 8 or as many as 26 or more. However, advanced vehicle designs incorporate innovative placement of batteries to avoid cargo space loss and better distribute the extra weight. The EV1 incorporates a T-shaped battery compartment "tunnel" central on the vehicle chassis. Most EV van models have battery packs positioned beneath the floorboards.

Lead-acid batteries, primarily newer improved technology types designed specifically for EV application, remain the battery of choice for most current OEM EV projects. Advanced battery technologies are a major focus of development and demonstration projects involving auto companies and battery suppliers. Nickel metal hydride batteries are progressing as the first non-lead acid battery technology to see commercial introduction. GM, Ford, and Honda are all pursuing this battery technology. Chrysler has built vehicles with nickel cadmium and nickel iron batteries, and Ford and others with sodium sulfur batteries, but these battery technologies are not near-term candidates for use in U.S. produced vehicles.

The first commercial EV using a non-lead acid battery technology is the Honda EV Plus, using nickel metal hydride batteries, beginning its introduction in 1997 (as a 1998 model). Some other battery technologies under development for EV application are listed in Table 12A. Industry-sponsored battery technology research efforts, by organizations such as the U.S. Advanced Battery Consortium, a combined effort of the U.S. auto makers, electric utilities and the federal government, are pursuing several of these battery technologies in search of the best options for higher energy and power density, longer life, and economy for future EV use. Today, however, it appears that various forms of lead-acid battery technology offer the most practical options for near-term commercial electric vehicle applications.

Some EV models carry an integral battery charger on board, while others rely on off-board chargers. Conductive (metal to metal) charging connections are favored by some manufacturers, while others (including GM) prefer an inductive charging system, which uses a plastic connector. Most EV models incorporate a regenerative braking system that recovers a portion of braking energy for battery charging. While some lead-acid batteries have previously required a battery fluid replacement system, newer technology lead-acid advanced battery packs are sealed and require no fluid replacement.

TABLE 12A

BATTERY TECHNOLOGY DEVELOPMENT FOR EV APPLICATIONS

Battery Technology	Developer(s)	OEM Involvement
Advanced Lead Acid	Bolder, Delphi, Electrosource, Exide, GNB, JSB, Matsushita, Yuasa, Optima, Hawker	Most OEMs with EV projects have, at one time or another, used lead-acid batteries
Lithium Ion (also known as Lithium Carbon)	Duracell, JSB, LIBES;, Saft, Sony, Varta, SRI	Ford, Honda, Nissan, Toyota, Peugeot
Lithium Iron Disulfide	Saft	
Lithium Polymer	3M	Chrysler, Ford, GM

Nickel Cadmium	Acme, Saft	Chrysler, Nissan, Toyota, Renault, Peugeot, Fiat, Mercedes Benz, Volvo, Mazda
Nickel Metal Hydride	JSB, Matsushita, Ovonic, Saft, Varta, Yardney	GM, Honda, Hyundai, Ford, Toyota, Daewoo
Sodium Nickel Chloride	AEG	BMW, VW, Fiat, Mercedes Benz
Sodium Sulfur	ABB, Silent Power	Ford, BMW, VW, Renault, Audi, Fiat, Suzuki, Ford (previously)
Zinc Air	Electric Fuel, Zinc Air Power	
Zinc Bromine	Powercell	

Hybrid electric vehicles rely less on battery storage in favor of an on-board auxiliary power unit to supply the electricity and/or to provide alternate or supplementary propulsion power. The most common hybrid EV concept under development employs some battery storage, with charging from an on-board combustion engine/generator, allowing partial battery-only operation, with the on-board generator supplying electricity when extended range or increased performance is needed. Combustion engines being experimentally applied in current OEM hybrid EV projects include conventional spark ignition (Otto Cycle) engines, direct-injected diesel engines, and turbine engines.

Fuel cells, which produce electricity electrochemically from fuel carried on-board, are also typically combined with at least limited battery storage, allowing the fuel cell to be sized below the vehicle's peak power requirements. Fuel cell EVs must also carry either a supply of hydrogen fuel for the hydrogen-oxygen reaction that produces electricity in the fuel cell, or a supply of a hydrogen-carrying fuel (such as methanol) and a reformer system to derive the hydrogen required for input to the fuel cell. Flywheel EV concepts would replace some or all of the battery electricity storage with electro-mechanical energy storage in the flywheel system, some utilizing an on-board combustion engine/generator and some relying on off-board electricity to "charge" (spin up) the flywheel.

Accessory features common to IC engine vehicles, including air conditioning, heater, power steering and power brakes, have required new engineering approaches for EVs (and most hybrid EVs) due to the absence (or reduction) of engine accessory drive power, waste heat, and engine vacuum. Electrically-powered systems employing electric motors or electric heat pumps to provide all of these functions are being developed for application to OEM EV models. Minimizing the auxiliary electricity usage for these accessory functions and other traditionally electric accessories (i.e., windshield wipers, lights, power windows, etc.), use of which can substantially reduce EV driving range, remains an important challenge for EV technology development.

2. Different Operational or Performance Features (from gasoline counterpart)

   The most significant aspects of EV operation that vary from operating characteristics of comparable gasoline vehicles include:

   - Reduced driving range (between rechargings) compared to gasoline vehicle refueling range. The much lower energy density of electric storage batteries vs. gasoline fuel (less than one-tenth the energy storage per volume of gasoline for the best battery technologies), even when compensated for by the higher efficiency of electric drive, results in limited driving ranges for current technology EVs with lead-acid batteries (typically between 50 and 100 miles with the maximum on-board battery capacity). The EV1 is specified by GM to have a 70 mile urban and 90 mile highway range, and the Ford Ranger pickup is specified to have a 58 mile urban range. The Honda EV Plus, with nickel metal hydride batteries, has an advertised range of 100 to 125 miles. Operation of accessories, driving in hilly terrain or using maximum speed or acceleration capability significantly reduce driving range, as will battery deterioration due to aging or abuse. Hybrid EVs allow longer driving ranges by carrying fuel on board to produce electricity for battery recharging or (less commonly) to power an engine for supplementary propulsion.

   - Vehicle acceleration and top speed. Most electric vehicle models commercially introduced and demonstrated to date (including OEM and converted models) have exhibited slower acceleration and lower top-end speed than IC engine counterparts. Ford's Ranger pickup is specified to accelerate from zero to 50 mph in 14 seconds, versus 12 seconds for the gasoline version. However, the GM EV1 has a specified zero to 60 mph time of under 9 seconds, which places it in the same acceleration bracket as many gasoline passenger cars. Both the Ranger and the EV1 have electronically governed top speeds of 70 to 80 mph.

   - Recharging/refueling procedure. EVs can typically be recharged wherever a compatible (inductive or conductive) electric connection is available, but the key consideration (as distinguished from gasoline or other alternative fuel refueling) is the time required. Full recharging is typically accomplished overnight, requiring from three to twelve hours, depending on the number and type of batteries and the charger voltage. The GM EV1, for example, can be fully recharged (from 15 percent capacity remaining) in about 3 hours using a 220 volt, 6.6 kw charger, but requires 12-15 hours for a full charge with a 110 volt, 1.2 kw charger. Most current vehicle/battery technologies allow for partial recharging, sometimes sufficient for a required trip length, that can be accomplished in a fraction of the full-charge time, although this may still involve one or more hours. Allowing the battery charge to run too low results in diminished vehicle performance and adversely affects battery life. Hybrid EVs will require on-board fuel storage and refueling with whatever combustion fuel is required by the auxiliary power unit. Fuel cell EVs, as noted earlier, require refueling either with hydrogen fuel or a hydrogen-carrying fuel.

C Other EV performance differences include the lack of IC engine noise, replaced by the (usually lower decibel level) electric motor "whine," and the "instant on" aspect of electric propulsion that substitutes for the idle aspect of IC engine operation. The ride and handling characteristics of some EV models may also be affected by the additional battery weight, although OEM designs attempt to compensate with enhanced suspension features. Hybrid electric vehicles may require driver interaction/selection of all-electric vs. combustion engine/generator-assisted modes, although some designs accomplish this function via computer-controlled electronics.

d. ***Maintenance and Reliability Features***

Electric vehicles clearly have fundamental technological differences that pose unique in-use maintenance and service considerations from those associated with IC engine vehicles. On-road experience with OEM electric vehicles is just beginning to measure differences with respect to the comparative maintenance and reliability features of EVs versus gasoline vehicles or other alternative fuel vehicles. Among the significant differences encountered with electric vehicle versus internal combustion engine vehicle maintenance are:

C A need for different service/repair facilities, expertise, replacement parts, training, etc. for servicing electric propulsion systems (electric motors, controllers, electronics).

C Less routine (scheduled) maintenance procedures associated with the mechanical propulsion system (i.e., engine oil changes, cooling fluids, drive belts etc.), replaced with new procedures associated with maintenance of the battery pack, including battery pack replacement at several-year intervals.

C An absence of maintenance, testing requirements etc. associated with emission control systems (except for hybrid vehicles).

e. ***Emission Features***

Battery-operated electric vehicles produce no engine exhaust or fuel vapor emissions, thus entitling them to CARB's designation as "zero-emission vehicles" (ZEVs), which are required to comprise 10 percent of major auto companies' sales in California beginning in 2003. However, the charging of electric vehicles from the electricity supply system is recognized to result in emissions from electricity generation, and the magnitude and location of these emissions associated with future EV operating scenarios continue to be evaluated and debated. Research to determine expected emissions associated with EV operation in different regions of California, and how these levels will compare with emissions from other low-emission vehicle technologies, has not provided consistent or complete results thus far.

Hybrid electric vehicles have emission-producing potential from operation of the combustion engine and from on-board fuel storage, and hybrid EVs are therefore at a disadvantage for obtaining CARB certification as ZEVs. CARB continues to study a potential "Equivalent Zero Emission Vehicle" (EZEV) standard for hybrid EVs or other technologies that can match the power plant emission levels predicted to result from battery operated EVs. While the small displacement, constant load and operating speed combustion engines typically adapted for use in hybrid EVs are considered capable of very low emission output, little test data to confirm actual emission performance of such engines operated with emission controls in hybrid EVs is yet available. Fuel cell EVs are generally considered to produce minimal emissions from the fuel cell itself, although including an on-board reformer to produce the needed hydrogen fuel from another (carbon-based) fuel would result in emissions of carbon compounds. Actual emission testing of fuel cell EVs has yet to be reported. Thus, it remains uncertain how the emissions of hybrid EVs may compare with low-emission vehicle standards or with other low-emission or "ultra-low" (combustion engine) vehicle technologies.

Analyses of the greenhouse gas implications of battery EVs have also produced somewhat inconsistent results, subject to some of the same uncertainties affecting comparisons of regulated emissions as discussed above. There appears to be general agreement however, that EVs offer a degree of total carbon emission reduction versus current technology gasoline vehicles, perhaps on the order of a 30 percent reduction in carbon emissions if all electricity for EV charging is assumed to be supplied by natural gas-fired power plants. Hybrid EVs pose greater difficulty for greenhouse gas evaluation, since they employ a variety of electricity source combinations involving different fuel-consuming technologies. Even fuel cells produce carbon emissions when the primary fuel source for the hydrogen fuel input is a carbon-based fuel, although, as noted earlier for hydrogen fuel vehicles, potential hydrogen production using renewable sources of energy offers a near complete reduction in carbon emissions.

f. ***Fuel Efficiency Features***

Analyses of the energy consumption levels expected from EVs, and the relative energy efficiency implications of EVs versus other alternative-fuel and conventional vehicles, also exhibit disparities in their results. Major reasons for this appear to be wide variation in reported unit electricity consumption rates for different EVs, ranging from one-fourth of a kilowatt-hour per mile to over 1 kWh/mile, and only a limited number of actual test results directly comparing EV energy usage with that of IC engine counterparts. Selection of an average projected EV electricity usage rate is thus subject to question. This becomes part of the uncertainty in projecting EV-related emissions, since the emissions caused by EV charging from the electricity supply system will be directly proportional to electricity used, unlike combustion engine vehicles, which are all regulated and controlled to the same grams-per-mile emission levels independent of their fuel consumption rates.

CARB has undertaken limited testing of EVs using similar procedures to those used for measuring gasoline (and alternative fuel) vehicle fuel economies (and emissions). Testing of several gasoline vehicles converted to EVs indicates an energy substitution ratio for EVs, compared to gasoline fuel economies measured for their gasoline counterparts using the similar federal test cycle, of about 12 kWh/gasoline gallon. Further work to develop more definitive estimates of future EV energy consumption relative to that of gasoline vehicles and other alternative fuel technologies is necessary.

Hybrid EVs present more complex energy efficiency considerations, since all or part of their electricity requirements are produced via an on-board generation system (i.e., a small, mobile electric power plant). Both small-sized otto cycle and diesel engines and combustion turbine engines are under development for hybrid EV application. Whether the efficiencies of various auxiliary power units for hybrid EVs will match or exceed efficiencies of the electricity supply system remains to be determined, as does the relative efficiency advantage of hybrid EVs versus advanced internal combustion engine vehicles. In general, hybrid EV combustion engines are expected to operate at more constant, closer-to-optimum rpm ranges than IC engines in conventional vehicles, allowing for greater fuel efficiency. Fuel cells applied to EVs are also expected to produce electricity at efficiencies that substantially exceed those of IC engines or today's electric power plants, but actual operating efficiencies of vehicular fuel cell applications have yet to be measured.

g. ***Cost Features***

The market price differences between new electric vehicles and gasoline counterpart vehicles are not well established and remain a controversial issue, since the first OEM EVs have only recently appeared in the U.S. marketplace. The GM EV1 and S-10 pickup, and the Ford Ranger EV pickup, are all being initially priced at about $34,000. As with other alternative fuel vehicle technologies in their early market introduction phases, these prices are set at levels intended to recover only a portion of total manufacturer development costs, and cannot be considered representative of actual costs of ultimate commercial production of such vehicles.

Much remains to be confirmed about market acceptance of EVs, including what price premiums (if any) the market will bear, and whether the higher cost of EVs will require some forms of subsidy. Hybrid EVs, including concepts employing combustion engine/generators, fuel cells or flywheel energy storage, remain in earlier development phases that make cost projections for such technologies even more uncertain than for battery-operated EVs.

Lower costs of electricity versus gasoline are expected to be a favorable operating cost category for EVs. The Commission's most recent estimate of expected off-peak electricity rates for EV charging (from about 5 to 10 cents per kilowatt-hour, depending on utility service area) represents more than a 50 percent savings at the lower end over forecast gasoline prices (using the previously noted energy substitution factor of 12 kWh electricity per gasoline gallon). Thus, a nominal EV consuming 0.4 kWh/mile (comparable to a 30 mpg gasoline vehicle) could save about 2 cents per mile in fuel expense, and in 15,000 miles of driving would realize a fuel expenditure savings of $300.

Battery replacement costs for electric vehicles are expected to be the most significant operating cost difference. Current battery technologies require replacement at 2 to 5 year intervals at a minimum cost of $2,000 per replacement cycle, adding 3 cents per mile or more to vehicle operating costs. Advanced battery technologies are expected to have considerably longer replacement cycles, but will likely have higher replacement costs. Any other differences in maintenance cost categories, including some maintenance items (e.g., oil changes) that favor EV technology, will likely be overshadowed by battery replacement costs, unless advances in battery technology can produce a "lifetime EV battery" at a cost competitive with today's batteries.

h. ***Challenges for Further Development***

The commercial promise of electric vehicles continues to confront some serious development issues, including:

C Adequate Battery Technology

Effective alternatives to the conventional lead-acid battery continue to be a critical and elusive component of EV commercialization efforts. More advanced versions of the lead-acid battery remain the best available technology, but still fall well short of performance and economic criteria considered necessary for general EV market introduction. Success of new battery technologies will be the key determinant of ultimate EV market acceptance.

- Incremental Vehicle Cost

  Despite hopeful predictions of lower future mass-production costs, introductory prices of early EV models reflect new technology development costs and low-volume production, and pose a dilemma for the auto industry and government with respect to how to make these vehicles affordable.

- Vehicle Operational Features

  In addition to the driving range limitation imposed by current battery technology, the change from internal combustion to electric propulsion involves some significant technical challenges with respect to vehicle performance (acceleration, hill climbing, top speed, etc.), accessories (air conditioning, heating, power steering, etc.), cargo capacities, and other areas where conventional vehicle characteristics continue to improve.

- Electricity Price Outlook

  Favorable electricity prices that would allow energy cost savings with EVs are predicated on low off-peak rates well below current (and forecast) nominal electricity prices. In some areas of the state, and under some charging conditions, electricity prices for EVs could prove higher than for gasoline and other fuels. The addition of highway excise taxes applied to other motor fuels would also decrease the competitive advantage enjoyed by electricity.

- Electric Utility Industry Involvement

  Similar to the earlier consideration for natural gas vehicles, development progress to date for EVs (and the necessary infrastructure) has been substantially supported and promoted by the efforts of the electric utility industry, with allowances for use of ratepayer funds authorized by government regulatory bodies, such as the PUC in California. Limitations now in effect on use of ratepayer funds may result in scaling back these types of utility investments.

C Emission Reduction Competition

The emission-reducing potential of EVs must be measured against continued progress in other areas of low-emission vehicle technology, some of which may offer similar emission reductions.

2. Heavy-Duty Vehicles

a. *Industry Project Summary (see Table 13)*

Development of electric buses, including transit buses, school buses and shuttle buses, is being pursued by a number of U.S., European and Japanese companies. U.S. companies with electric bus projects include APS Systems, Blue Bird Corp., Orion Bus Industries, Bus Manufacturing USA, El Dorado National, Gillig, Neoplan, New Flyer Industries, Novabus, Specialty Vehicle Manufacturing, Thomas Built Buses, and Nordskog Electric Vehicles. European companies Volvo and Van Hool, the Japanese company Toyota, and the Chinese company Yuanwang are also involved in electric bus development.

TABLE 13
ELECTRIC HEAVY-DUTY VEHICLE DEVELOPMENT BY OEM COMPANIES

Company	Model	Status
APS Systems	E Transit bus	E limited production
Blue Bird/Northrup Grumman	E Transit bus, School bus	E limited production
Bus Mfg. USA	E Hybrid bus	E demonstration
El Dorado Natl.	E Transit bus	E demonstration
Isuzu (Japan)	E ELF 2-ton truck	E prototype
Kenworth	E Waste Hauling truck	E under development
Neoplan	E Hybrid bus	E under development
New Flyer	E Fuel cell bus	E under development
Nordskog (div. of Electricar)	E Shuttle bus	E limited production
Novabus	E Fuel cell transit bus	E under development
Orion Bus Industries	E Hybrid transit bus	E demonstration
Specialty Vehicle	E Shuttle bus	E demonstration
Thomas Built	E Transit bus	E under development

Toyota (Japan)	E Hybrid bus	E prototype
Van Hool (Belgium)	E Fuel cell bus	E concept vehicle
Volvo (Sweden)	E Truck and bus	E concept vehicle

Kenworth Truck Company of the U.S. and the Japanese company Isuzu are pursuing the only reported developments of electric heavy-duty truck models. Among the approximately 20 different projects undertaken by the previously mentioned companies,

about half involve battery operated vehicles and half involve hybrid electric technology, including three fuel cell buses.

c. ***Summary of Vehicle Technology Characteristics***

The previous discussion of technology characteristics for light-duty electric vehicles applies for the most part to heavy-duty EV technology as well.

d. ***Challenges for Further Development***

The previous discussion of challenges for further development of light-duty electric vehicles generally applies to heavy-duty applications, with the following additional comments:

C Many heavy-duty vehicle applications involving long-distance travel and/or demanding duty cycles present even more challenging problems for the limited range and recharging requirements of battery electric vehicle technology.

C Smaller volume production of heavy-duty vehicles may make it more difficult to reduce the incremental cost of electric models.

C The lower cost of diesel (vs. gasoline) fueling common to most heavy-duty vehicle applications reduces the operating cost advantage of electricity.

Appendix to Section I

Automotive Industry Alternative Fuel Vehicle Development Project Data Base

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
ADAM OPEL AG	Germany	Twin	1992	PLANNING	1	0.8	I-3	Compact Van	ELEC HYBR	Li-C battery system or an interchangeable IC engine module (800cc, 3 cyl.)	Clean Fuels Rep, 9/92; Wards Auto World, 4/92
AUDI AG	Germany	Duo	1996	CONCEPT		1.9		Compact Pass. Car	ELEC HYBR	Latest of Audi's series of hybrid model devel. Shown at 1996 Berlin Auto Show. Based on the A4 Avant Sta. Wgn. Parallel hybrid w/ D.I. turbo-diesel engine & elec. motor, lead-acid batteries. Scheduled for European intro. Fall 1997. 500 expected first yr.	Clean Fuels Rep, 9/92; Mechanical Engineering, 8/90; Autom. News, 2/25/91, 10/28/96
BMW	Germany	320	1990	DEMONSTRATION	10			Subcompact Pass. Car	ELEC	Na-S batteries	Autom. News, 2/25/91
BMW	Germany	E1	1993	CONCEPT	1			Compact Pass. Car	ELEC HYBR	Development continuing in Germany. 2nd generation vehicle. Hybrid w/ Al space frame, plastic body. NaNiCl batteries.	Autom. News, 9/13/93, 4/1/96; Autom. Engrg. 11/93
BMW	Germany	E2	1992	PROTOTYPE				Compact Pass. Car	ELEC		Clean Fuels Rep 9/92
BMW	Germany	735iL	1990	CONCEPT	1	3.5	I-6	Mid-Size Pass. Car	ELEC HYBR	Liquid hydrogen storage.	Popular Science 4/6/90
CHRYSLER CORP.	Michigan	TEVan	1990-95	PREVIOUS LIMITED AVAILABILITY	52			Mini Van	ELEC	Based on Caravan/Voyager. Demo'd in CA & other states w/ NiFe & Ni Cd batteries. 52 vehicles w/ Pb-acid batteries sold to elec.utility fleets,1993-94 (6 in CA). Discontinued in 1995. 2nd generation vehicle (EPIC) being developed.	Clean Fuels Rep, 9/92; Autom.News, 2/25/91, 9/20/93; Chrysler Corp. AFV Quarterly, Winter 1995-96
CHRYSLER CORP.	Michigan	EPIC	1997	LIMITED AVAILABILITY	20			Mini Van	ELEC	Stands for Elect. Powered Interurban Commuter. Follows TEVan program, uses redesigned Caravan/Voyager platform, Pb-acid batteries. 20 built on regular assembly line; 17 to be operated in CA by U.S. military & So. CA Edison beg. late 1997.	Chrysler Corp. AFV Quarterly, Winter 1995-96, Fall 1996, Spring 1997; Autom. News 4/1/96; Clean Fuels Rep. 2/97
CHRYSLER CORP.	Michigan	Patriot	1994	CONCEPT				Open-Wheel Race Car	ELEC HYBR	Experimental vehicle w/ LNG-fueled turbine engine/generator & flywheel storage; originally planned for entry in motor racing events. Program discontinued in 1996.	Autom. Engrg. 2/94, 12/94; Green Car Journal 6/96
CHRYSLER CORP.	Michigan	Intrepid ESX	1996	CONCEPT		1.8	3	Mid-Size Pass. Car	ELEC HYBR	Chrysler's development vehicle for the federal PNGV program. Series hybrid w / 1.8 liter 3-cyl, 80 HP turbo-diesel engine/generator, lead-acid batteries, aluminum body. First displayed at 1996 Detroit Auto Show.	Autom. News 1/8/96, 4/8/96; Wards Auto World 2/96; Autom. Engrg. 3/96, 5/96, 11/96; Chrysler Corp. AFV Quarterly, Winter 1997

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
CHRYSLER CORP.	Michigan	LHX	1997	DEVELOPMENT					ELEC FUEL CELL	Plans annouced at the 1997 Detroit Auto Show for joint project w/ Arthur D. Little Inc. & Delphi Systems to develop a fuel cell vehicle that uses gasoline fuel. Running vehicle planned within two years.	Sacramento Bee 1/7/97; Autom. News 1/6/97; Clean Fuels Rep. 2/97
DAEWOO	South Korea	DEV-2, DEV-4; DACC-II; Green	1995	CONCEPT				Pass. Cars	ELEC	Concept vehicles displayed at 1995 Seoul Auto Show. Pb-acid & Ni-metal-hydride batteries. Latest vehicle, DEV-4, is conversion of Cielo mid-size sedan.	Autom. Engrg. 8/95, 9/96
DAIHATSU MOTOR CO. LTD.	Japan	Micro Van & Pickup	1995	AVAILABLE IN JAPAN				Small Van & Pickup	ELEC	Electric versions of two of company's gasoline models. Available only in Japan.	Autom. Engrg. 8/95
DAIHATSU MOTOR CO. LTD.	Japan	Mini Sway	1995	AVAILABLE IN JAPAN				Single Seat Micro Car	ELEC	One-seater, classified as a motorbike. Being test marketed in Japan in cooperation with Kansai Electric Power Co.	Clean Fuels Rep 11/95
DAIHATSU MOTOR CO. LTD.	Japan	Hybrid EV Sedan	1993	CONCEPT	1			4-Dr. Pass. Car	ELEC HYBR	Hybrid w/ lean-burn 660cc gasoline engine aux. power unit. Ni-hydrogen batteries. Displayed at the 1993 Tokyo Motor Show.	Autom. Engrg. 2/94
DAIHATSU MOTOR CO. LTD.	Japan	P100	1996	CONCEPT				1 Pass. Car	ELEC	Plastic bodied mini-car. Lead-acid batteries. 6 vehicles tested by the public in Osaka.	Clean Fuels Rep. 4/96, 2/97
FIAT AUTO	Italy	500 Series Cinquecento Elettra	1995	AVAILABLE IN ITALY				Subcompact Pass. Car	ELEC	Pb-gell or Ni-Cd batteries. Available in Italy w/gasoline or electric power.	Clean Fuels Rep 2/95
FIAT AUTO	Italy	Downtown	1993	CONCEPT				Micro Pass. Car	ELEC	Na-S batteries. Aluminum body & frame.	Autom. News, 5/1/93
FIAT AUTO	Italy	Ducato Electra		PLANNING				Van	ELEC	Pb-acid batteries; joint venture w/ Peugeot/Citroen; offered to utility companies	
FIAT AUTO	Italy	Panda Eletras	1990	AVAILABLE IN ITALY				Subcompact Pass. Car	ELEC	Flooded Pb-acid/gel cell Pb-acid/Ni-Cd/and Na-S batteries; only available in Italy.	Clean Fuels Rep 2/95
FIAT AUTO	Italy	Zic	1995	PROTOTYPE				4-Seat Pass. Car	ELEC	Experimental; Al spaceframe; composite body; NiNaCl batteries; Sponsored by Italian Natl Research Council.	Autom. Engrg. 8/95; Clean Fuels Rep 2/95, 11/95
FORD MOTOR CO.	Michigan	Escort	1993	CONCEPT	1			Compact Pass. Car	ELEC HYBR	Parallel hybrid w/3 cyl. 2-stroke engine. Devel. w/ German Inst. of Autom. Engr. Displayed at 1993 Frankfort Auto Show.	Autom.Engrg. 11/93

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
FORD MOTOR CO.	Michigan	Aerostar ETX II	1989	PROTOTYPE	2			Compact van	ELEC	Demonstration with U.S. DOE.	Autom. News, 2/25/91
FORD MOTOR CO.	Michigan	Ecostar	1993	DEMONSTRATION	103			Compact van	ELEC	52 vehicles used in demo in 12 fleets in U.S. & Canada; 26 vehicles in Company testing; others in utility fleets around the world. 900,000 driving miles accumulated. NaS batteries	Clean Fuels Rep, 6/92; Utility Fleet Mgmt. 6/95; Autom. News 4/1/96; Ford press release 8/5/96
FORD MOTOR CO.	Michigan	Ghia Connecta	1992	CONCEPT	1			Compact van	ELEC	Based on the Ecostar platform. No plans for marketing the vehicle.	Autom. News, 1/6/93
FORD MOTOR CO.	Michigan	LN7	1985	CONCEPT	1				ELEC		Autom. News, 2/25/91
FORD MOTOR CO.	Michigan	Ranger Pickup	1996	AVAILABLE FOR ORDERING				Pickup	ELEC	Initially supplied by Ford's "Qualified Vehicle Modifier", TDM Corp. and purchased by Cities of Santa Clara, Milpitas, Morgan Hill & Gilroy. 1998 model year factory-produced version available for ordering; first factory prod. Dec 1997. Pbacid batteries	Autom. News 9/95, 4/1/96; Clean Fuels Rep. 9/96, 2/97; Green Car Jour. 10/96, 5/97; Automotive Fleet 2/97
FORD MOTOR CO.	Michigan	EVent	1995	CONCEPT				4-Seat Pass. Car	ELEC	Displayed at 1994 Elect. Vehicle Symposium	Clean Fuels Rep 11/95
FORD MOTOR CO.	Michigan	Synergy 2010	1996	CONCEPT				6-Pass. Sedan	ELEC HYBR	Ford's initial entry in the federal PNGV Program. Hybrid w/ 1 liter direct-injected diesel engine/generator, flywheel energy storage, all aluminum unibody constr. Other power source options studied, incl fuel cells. Displayed at 1996 Detroit Auto Show.	Wards Auto World 1/96, 2/96, 3/97; Autom. Engrg. 3/96, 11/96; Clean Fuels Rep. 2/97
FORD MOTOR CO.	Michigan	P2000	1997	DEVELOPMENT		1.2	4	Mid-Size Pass. Car	ELEC HYBR	Hybrid combining aluminum direct-injected diesel and electric motor propulsion modes. Al & other light-weight materials. Latest Ford PNGV project. Running prototype planned by late 1997.	Autom. Engrg. 5/97; Popular Science 7/97
GENERAL MOTORS CORP.	Michigan	Griffon Van	1986	DEMONSTRATION				Full Size Cargo or Pass. Van	ELEC	Demonstration in various fleets in CA and elsewhere.	
GENERAL MOTORS CORP.	Michigan	Geo Storm	1993	CONCEPT	2			Subcompact Pass. Car	ELEC	Pb-acid batteries	Green Car Jour. 12/91
GENERAL MOTORS CORP.	Michigan	Impact	1994	DEMONSTRATION	50			Compact Pass. Car	ELEC	Pb-acid batteries. Demonstration w/ public participants, utilities and gov't entities in 2-yr preview program. Forerunner of the EV1.	Clean Fuels Rep, 9/92; Elect. Veh. Assoc. of the Americas newsletter, 1/93; Utility Fleet Mgmt. 6/95

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
GENERAL MOTORS CORP.	Michigan	EV 1	1996	LIMITED AVAILABILITY				Sport Coupe	ELEC	Limited commercial intro. began Dec. '96. Offered for lease through 25 selected Saturn dealers in L.A., San Diego, Phoenix & Tucson. 175 leased in first 5 months.	Wards Automotive Reports 1/8/96; Autom. Engrg. 6/96; Green Car Jour. 2/96, 5/97; Car & Driver 10/96; G.M. press release 12/96
GENERAL MOTORS CORP.	Michigan	S-10 Pickup	1997	AVAILABLE				Small Pickup	ELEC	First '97 production models delivered to some U.S. electric utilities. First shown at Edison Electric Institute Fleet Managers EV Conference, 8/95. Lead-acid batteries. 900 reportedly on order by electric utilities.	New Fuels Rep. 8/14/95; Wards Automotive Reports 1/8/96; Green Car Journal 3/96; Autom. Engrg. 7/97
GENERAL MOTORS CORP.	Michigan	Lumina APV Van		CONCEPT	1			Mini Van	ELEC	Pb-acid batteries	Green Car Jour. 12/91
GENERAL MOTORS CORP.	Michigan	Lumina Hybrid	1995	DEVELOPMENT				Pass. Car	ELEC HYBR	Hybrid EV project using Chevrolet Lumina sedans; part of the federally-sponsored "Partnership for a New Generation of Vehicles" program. Testing of two versions underway, one using a Stirling engine/generator, one using a turbine engine/gen..	Autom. News 11/13/95, 1/13/97; Clean Fuels Rep. 2/97
GENERAL MOTORS CORP.	Michigan	HX3	1992	PROTOTYPE				Van	ELEC HYBR	Pb-acid batteries w/ IC engine generator	Battery & EV Technol., 11/92
GRUMMAN CORP.	New York	Route Mate Van	1994	PROTOTYPE	6			Delivery Van	ELEC HYBR	Natural gas-fueled hybrid vehicle w/Al body. First vehicles operated by Long Island Lighting (N.Y.) beg. 1994.	Green Car Jour. 2/94
HONDA	Japan	CUV-4	1995	PROTOTYPE	5			Subcompact Pass. Car	ELEC	Stands for "Clean Urban Vehicle". Advanced prototype using Civic hatchback body on special chassis. Pb-acid batteries. 5 vehicles in 2-3 yr field test at SCE, PG&E, Sacto Metro Airport.	Autom. Engrg. 1/95, 3/95; New Fuels Rep. 10/23/95; Autom. News 4/1/96
HONDA	Japan	EVX	1993	CONCEPT	1			Subcompact Pass. Car	ELEC	Displayed at the 1993 Tokyo Motor Show and the 1994 L.A. Auto Show. Pb-acid batteries.	Green Car Jour. 12/93, 2/94; Autom. Engrg. 2/94
HONDA	Japan	EV Plus	1997	LIMITED AVAILABILITY				4 Pass. Car	ELEC	Based on CUV-4 prototype. American Honda Motor Co. beginning limited 1997 intro.;about 300 units to be available for leasing through selected Honda dealerships in L.A. area & Sacto. over next several years. Nickel-metal-hydride batteries.	Autom. News 4/8/96,4/15/96; J.D. Power CA Report 4/96; Green Car Journ. 5/96, 1/97; Autom. Engrg. 7/96; Clean Fuels Rep. 2/97
HYUNDAI	South Korea	FGV-1 (Accent)	1995	CONCEPT	1			Compact Pass. Car	ELEC HYBR	Based on the Accent sedan platform. Ni metal hydride batteries. Displayed at the 1995 Seoul Auto Show. Tested by CARB.	Clean Fuels Rep, 9/92; Autom. Engrg. 8/95

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
KIA MOTORS	South Korea	KEV-4	1995	CONCEPT	1			Commuter Car	ELEC HYBR	Hybrid w/800cc Aux. Power Unit. Pb-acid batteries. Displayed at 1995 Seoul Auto Show.	Autom. Engrg. 8/95
KIA MOTORS	South Korea	Pride	1994	PROTOTYPE				2 Pass. Car	ELEC	Electric version of company's gasoline Pride. Some being operated by Korea Electric Power Co.	Autom. Engrg. 1/95
MAZDA	Japan	Roadster EV	1995	CONCEPT	1				ELEC	High performance EV based on the Eunos roadstar, developed jointly with Chugoku Electric Power Co. NiCd batteries	Clean Fuels Rep 11/95
MAZDA	Japan	Miata	1993	DEMONSTRATION				2 Seat Pass. Car	ELEC	Electric version of company's gasoline model. 3 vehicles tested in Chugoku Electric Co. fleet, Japan. Displayed at EV Symposium, Anaheim, CA 12/94. NiCd batteries.	Autom. Engrg. 6/93; Autom. News 4/1/96; Elect Vehicle Assoc. of the Americas newsletter 5/95
MAZDA	Japan	HR-X	1991	CONCEPT		0.5	R	Compact	ELEC HYBR	Hybrid powered by a single chamber rotary named the H-RE10X with hydrogen fuel, regenerative braking and a Ni-H battery storage system. Metal hydride storage.	Autom. Engr 6/93
MERCEDES-BENZ	Germany	190E & MB100	1994	DEMONSTRATION	20			Compact Pass. Car & Van	ELEC	20 vehicles being tested on German island of Rugen as part of German Federal Ministry for Research program. NiCd & NaNiCl batteries.	Autom. News 2/25/91; Clean Fuels Rep 9/92; Daimler-Benz Environmental Rep. 8/95
MERCEDES-BENZ	Germany	Sprinter Van	1994	AVAILABLE IN GERMANY				Van	ELEC	Van available in Germany w/ choice of gasoline, diesel, or electric drivetrains	Daimler-Benz Env. Rep. 8/95
MERCEDES-BENZ (DAIMLER-BENZ)	Germany	NeCar I & NeCar II	1994/96	CONCEPT	2			Utility/Pass Van	ELEC FUEL CELL	1st & 2nd generation experimental vehicles using PEM fuel cells from Ballard Power Systems (Vancouver, B.C.). NeCar I (1994) based on MB 100 van. NeCar II (1996) based on V Class van w/ gaseous H2 carried in roof tanks. Ongoing test program in Germany.	Daimler-Benz Env. Rep. 1995,1996; Daimler-Benz High Tech Rep. 1996; Green Car Journal 6/96; Autom. News 5/20/96; Autom. Engrg. 7/96; Car & Driver 9/96; Clean Fuels Rep. 9/96
MERCEDES-BENZ/SMH	Germany/Switzerland	Smart Minicar	1994	PROTOTYPE				Mini Pass. Car	ELEC & ELEC HYBR	Joint project of Mercedes-Benz & SMH (maker of "SWATCH"). Displayed at 1994 Geneva Motor Show. Being tested in Germany. Initial prod. planned for Spring 1998 w/gasoline engine. EV and hybrid versions under devel. for possible availability after 2000.	Autom. Engrg. 6/94; Autom. News 11/13/95, 3/11/96, 4/29/96, 10/14/96
MITSUBISHI	Japan	ESR	1993	CONCEPT				Compact Pass. Car	ELEC HYBR	Hybrid w/ 1.5 liter "Miller Cycle" engine. Alkaline batteries. Displayed at 1994 L.A. Auto Show.	Autom. News, 10/18/93; Green Car Jour. 2/94, 3/94

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
MITSUBISHI	Japan	Chariot/Expo	1995	PROTOTYPE	2			Mini Van	ELEC HYBR	Hybrid w/1.5 liter 4-cyl gasoline-fueled aux/ power unit, lead-acid batteries. 2 vehicles delivered to CARB in 1995 for 30-month test	Wards Auto World 7/95; Autom. News 6/19/95, 4/1/96
MITSUBISHI	Japan	HEV	1995	PROTOTYPE	4			Mini Van	ELEC HYBR	Hybrid w/ 1.5 liter CNG-fueled aux. power unit. Lithium-ion batteries. Displayed at 1995 Tokyo Motor Show. First vehicle destroyed by fire 1/3/96 shortly after arriving in CA for testing; 3 others tested in Japan.	Autom. News 10/23/95, 1/29/96, 3/25/96; Autom Engrg. 2/96; Clean Fuels Rep. 2/97
NISSAN MOTOR CORP.	Japan	Cedric/Gloria	1993	AVAILABLE IN JAPAN	50				ELEC	Pb-acid batteries	Autom. News, 10/26/92
NISSAN MOTOR CORP.	Japan	FEV (Future Electric Vehicle) & FEV-II	1992-95	CONCEPT				Compact 4 Pass. Car	ELEC	Originally used NiCd batteries. FEV-II, displayed at 1995 Tokyo Motor Show & 1996 L.A. Auto Show, uses lithium-ion batteries by Sony. Developed by Nissan Design Intl. (So. CA).	Clean Fuels Rep, 9/92, 4/96; Autom. News 10/23/95, 4/1/96; Green Car Jour. 12/95; Autom. Engrg. 2/96
NISSAN MOTOR CORP.	Japan	Avenir	1995	DEMONSTRATION	15			Compact Sta. Wagon	ELEC	Retrofitted production vehicle being tested in the Kyushu Elec. Power Co. fleet in Japan	Green Car Jour. 12/95
NISSAN MOTOR CORP.	Japan	Micra	1989	CONCEPT	1				ELEC	Fe-Ni-Al batteries	Autom. News, 2/25/91
NISSAN MOTOR CORP.	Japan	Sun Favor		CONCEPT	1			Micro Pass. Car	ELEC	Mono-crystal silicon solar cells, three wheeler	Clean Fuels Rep, 9/92
NISSAN MOTOR CORP.	Japan	Prairie Joy	1995	DEMONSTRATION	25			Minivan	ELEC	Displayed at 1995 Tokyo Motor Show. 25 in service in Japan. Lithium Ion batteries by Sony. Initial offering to Japanese fleet mkt. planned for Spring 1997; Larger version planned for U.S. intro. in early 1998. Limited testing in U.S. scheduled for 1997.	1995 Annual Rep. of the Intl. Energy Agency Implementing Agreement for Electric Vehicles; Green Car Journ. 8/96; Clean Fuels Rep. 9/96
NISSAN MOTOR CORP.	Japan	Nissan EV	1996	DEVELOPMENT				4 Pass. Minivan	ELEC	Incorporates electric powertrain of Prairie Joy in all new, larger platform designed for either gasoline engine or electric motor. Li-ion batteries. 30 vehicle demo fleet scheduled for CA in 1998, followed by addition 90 demo vehicles in 1999-2000.	Nissan news release 10/14/96; Clean Fuels Rep. 2/97

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
NISSAN MOTOR CORP.	Japan	HEV	1997	DEVELOPMENT				Pass. Car	ELEC HYBR	Hybrid pass. car development using 1 liter gasoline engine/generator; Lithium Ion batteries by Sony.	Clean Fuels Rep. 2/97
PSA (PEUGEOT CITROEN)	France	205 Sedan	1990	DEMONSTRATION	30			Pass. Car	ELEC	Demonstrated in France	Autom. News, 2/25/91
PSA (PEUGEOT CITROEN)	France	Citroen C-15 Van	1991	DEMONSTRATION	50			Van	ELEC	Demonstrated in Hong Kong	Autom. News, 2/25/91
PSA (PEUGEOT CITROEN)	France	J5 Delivery Van	1990	DEMONSTRATION	25			Van	ELEC	Demonstrated in France	Autom. News, 2/25/91
PSA (PEUGEOT CITROEN)	France	Peugeot 106; Citroen AX	1995	AVAILABLE IN FRANCE				Compact Pass. Car	ELEC	Gasoline models that became available in electric versions in 1995 in France. Over 1,000 electric models reportedly produced as of 2/96. Uses NiCd batteries.	Clean Fuels Rep, 9/92; Green Car Jour. 2/94; Calstart Connection 4/96
PSA (PEUGEOT CITROEN)	France	Citroen Citela	1992	PROTOTYPE				4-Seat Commuter	ELEC	Plastic body prototype w/ NiCd batteries.	Green Car Jour. 4/92
PSA (PEUGEOT CITROEN)	France	PSA Tulip	1995	CONCEPT	1			City Car/Station Car	ELEC	Concept vehicle displayed at 1995 Frankfort Motor Show	Autom. Engrg. 9/95
PSA (PEUGEOT CITROEN)	France	Peugeot Ion	1995	CONCEPT	1			Pass. Car	ELEC	NiCd batteries	Autom. Engr 2/95
PSA (PEUGEOT CITROEN)	France	Citroen Saxo Electrique	1996	PROTOTYPE				Pass. Car	ELEC	Displayed at 1996 Paris Auto Show. NiCd batteries.	Autom. News 9/30/96
PSA (PEUGEOT CITROEN)	France	Peugeot Touareg	1996	CONCEPT				Two-Seat Pass. Car	ELEC	Displayed at 1996 Paris Auto Show. Features vacuum-formed honeycomb carbon structure.	Autom. News 9/30/96
RENAULT	France	Express Electrique	1994	DEMONSTRATION	10			Lt. Duty Vans	ELEC	Demonstration in City of Goteborg, Sweden. NiCd, NaS, Lead gel batteries.	Clean Fuels Rep 2/95

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
RENAULT	France	Clio Electrique	1995	AVAILABLE IN FRANCE				Subcompact Pass. Car	ELEC	Electric version being produced (at a rate of 2/day) on the same assembly line as the conventional vehicle model. 41 reportedly sold in 1st half of 1996. Uses NiCd batteries (SAFT).	Calstart Connection 4/96; Autom. News 10/21/96
RENAULT	France	Next	1997	CONCEPT				5-Pass. Car	ELEC HYBR	Parallel hybrid w/ ft. wheel dr. gasoline engine & rear wheel electric motors. Al & carbon fiber construction. Has been test-driven in Paris.	Autom. Engrg. 1/97; Clean Fuels Rep. 2/97
RENAULT	France	Pangea	1997	CONCEPT				4x4 Minivan	ELEC HYBR	Hybrid electric concept van displayed at the 1997 Geneva Motor Show. Employs an LPG-fueled turbine engine-generator.	Ward's Auto World 4/97; Car & Driver 6/97; Autom. Engrg. 5/97; Clean Fuels Rep. 6/97
SAMSUNG MOTORS CORP.	South Korea	SEV-III, SEV-IV	1994/ 1996	PROTOTYPE				3 dr. Hatchback Pass. Car	ELEC	Al frame. plastic body. Pb acid batteries. 40 planned for use in Seoul. Parent co. is S. Korea's largest industrial conglomerate, poised to enter the auto business w/ Nissan; first plant under construction. Design studio in S. CA.	Autom. Engrg. 9/94, 9/96; Green Car Jour. 1/97
SSANGYONG MOTOR CO.	South Korea	CCR-1	1995	CONCEPT	1			Pass. Car	ELEC	Pbacid batteries. Displayed at 1995 Seoul Auto Show. Ssangyong is a small truckmaker affiliated with Mercedes-Benz.	Autom. Engrg. 8/95
SUBARU	Japan	Elcapa	1995	CONCEPT	1			4-dr. Mini Pass. Car	ELEC HYBR	Parallel hybrid -- can operate w/gasoline engine, electric motor or both together. Lead-acid batteries plus a condenser storage system. Displayed at 1995 Tokyo Motor Show.	Autom. News 10/23/95; Autom. Engrg. 2/96
SUZUKI	Japan	EE-10	1993	CONCEPT	1			4-Seat Pass. Car	ELEC HYBR	Parallel hybrid w/methanol-fueled SOHC 660cc engine. NaS batteries. Displayed at 1993 Tokyo Motor Show.	Autom. Engrg. 2/94
TAYLOR-DUNN	Anaheim, California	Electruck	1993	AVAILABLE IN FOREIGN MARKETS	400			2,200 lb. Delivery Vehicle	ELEC	Company's 1st on-road vehicle; 400 sold to Mexico City Pepsi Cola subsidiary. Company has produced 100,000 industrial EVs.	Green Car Jour. 9/93
TOYOTA MOTOR CORP.	Japan	Crown Majesta	1993	CONCEPT					ELEC	Pb-acid batteries	Autom. News, 10/26/92
TOYOTA MOTOR CORP.	Japan	Town Ace	1990	DEMONSTRATION	1			Mini Van	ELEC	Ni-Cd batteries; demonstrated in Japan	Autom. News, 2/25/91
TOYOTA MOTOR CORP.	Japan	EV-50	1993	CONCEPT				4 Pass. Commuter Car	ELEC	Displayed at 1993 Tokyo Motor Show & 1994 L.A. Auto Show	Autom. Engrg. 2/94; Green Car Jour. 12/93, 2/94

COMPANY NAME	COMPANY LOCATION	MODEL NAME	YEAR	DEVELOPMENT STATUS	QUANTITY	ENGINE SIZE (liters)	ENGINE TYPE	VEHICLE TYPE	FUEL	NOTES	REFERENCES
TOYOTA MOTOR CORP.	Japan	RAV4L	1995	AVAILABLE IN JAPAN				Sport-Utility Vehicle	ELEC	Limited sales in Japan beg. Fall 1996 (100 vehicles, 1st yr)) 20 tested in U.S. field-test. Limited avail. to U.S. fleet buyers beg. late 1997; 700 expected to be built by 2000. Ni-metal hydride batteries from Matsushita.	Autom. News 1/29/96, 4/1/96,4/15/96,10/14/96, 7/7/97; H2 & Fuel Cell Letter 2/96; J.D. Power CA Rep 4/96; Green Car Journal 3/96,6/96; Autom. Engrg. 7/96, 2/97; Calstart Newsnotes 7/26/96; Clean Fuels Rep. 2/97
TOYOTA MOTOR CORP.	Japan	FCEV	1996	CONCEPT				Sport-Utility Vehicle	ELEC FUEL CELL	Displayed at 1996 Intl. Elec. Vehicle Symposium, Osaka, Japan. Based on the RAV4 platform. PEM fuel cell. Features new H2-absorbing metal hydride alloy fuel storage technology developed by Toyota.	Autom. News 10/14/96; Autom. Engrg. 2/97; Clean Fuels Rep. 2/97
TOYOTA MOTOR CORP.	Japan	HEV	1995	CONCEPT				4-Seat Pass. Car	ELEC HYBR	Employs Toyota's Energy Mgmt. System (EMS), parallel hybrid drive w/ direct injected gasoline engine, in-line electric motor/generator. Japan market intro. planned for 1998. U.S. plans being considered.	Autom. Engrg. 2/96, 7/97; Clean Fuels Rep. 2/97; Green Car Jour. 7/97
VOLKSWAGEN AG	Germany	Jetta	1991	DEMONSTRATION	110			Compact Pass. Car	ELEC ELEC HYBR	Na-S & Pb-Acid batteries. Demonstrated in Germany. Diesel/Electric. Demonstrated in Ger. and Switz.	Autom. News, 10/26/92
VOLKSWAGEN AG	Germany	Chico	1995	PROTOTYPE				Compact Pass. car	ELEC HYBR	Gasoline/electric	Clean Fuels Rep, 4/93
VOLKSWAGEN AG	Germany	Golf	1992	DEMONSTRATION	20			Compact Pass. Car	ELEC HYBR	Parallel hybrid electric/ diesels tested in Zurich.	Clean Fuels Rep, 9/92; 2/95
VOLKSWAGEN AG	Germany	Concept 1	1994	CONCEPT				Subcompact Pass. Car	ELEC	Concept vehicle; modernized version of original VW "Beetle". Three drivetrains: DI diesel. electric, hybrid. Displayed at 1994 Detroit Auto Show. NaNiCl batteries.	Autom. Engrg. 2/94
VOLVO	Sweden	ECC	1992	CONCEPT				4 dr. Pass Car	ELEC HYBR	Hybrid w/ gas turbine engine & high-speed generator. Displayed at 1992 Paris Auto Show and in So. CA. NiCd batteries.	Green Car Jour. 12/92, 2/93
VOLVO	Sweden	850 Sedan	1995	CONCEPT				4 Dr. Pass Car	ELEC HYBR	Can be operated in pure-EV mode or with trailered engine-generator. NiCd batteries.	Green Car Jour. 10/95

Section II - Automotive Fuel Economy Technology Trends

Advances in automotive efficiency-improving technologies continue to be pursued on numerous fronts by both the mainstream OEM auto companies and outside organizations. While past pressures for higher fuel economy prompted by increasing Corporate Average Fuel Economy (CAFE) standards and fuel price spikes have greatly diminished, auto makers are still motivated to achieve progress in energy efficiency in order to: (1) maintain compliance with the prevailing CAFE standard (27.5 mpg average for each company's passenger car sales), while meeting new safety and emission requirements that negatively affect fuel economy, and (2) respond to demands from the marketplace and competitive industry pressures to provide favorable fuel economy as part of an overall package of consumer-desired vehicle attributes including size, performance, safety and accessory features.

The growing market shares of light-duty trucks and vans, which are subject to a separate CAFE standard (currently 20.7 mpg) and rulemaking process, adds further inducement for efficiency progress. Truck and van models account for five of the top ten selling light-duty vehicles in California and an increasing fraction of all vehicle sales, over one-third as of the 1995 model year. These classes of vehicles have been subject to less stringent standards than passenger cars in all categories of regulated technology, including emissions, safety and fuel economy, but with their increasing popularity as general use vehicles, light trucks and vans are the focus of efforts to close the gap with passenger cars in all these technology areas. While higher CAFE standards are not now under active consideration for either automobiles or trucks, the motor vehicle industry remains in the mode of developing and selectively applying efficiency-improving technologies in response to the existing (albeit reduced) level of marketplace interest, and in anticipation of potential resurgence of fuel economy as a regulatory and consumer priority. Even in the heavy-duty truck sector, which has never been subject to fuel economy standards, considerable industry interest in efficiency-improving technologies is in evidence, apparently a reflection of marketplace interest.

Since pre-CAFE regulation and pre-energy crisis times (i.e., since the early 1970s) the average fuel economy of new passenger cars sold in the U.S. has roughly doubled, from about 14 mpg to about 28 mpg (based on U.S. EPA city/highway tests). No separate estimate exists for cars sold in California; however, comparing the state versus national sales mix suggests that the average fuel economy of cars sold in the state is at least equal to, if not somewhat higher than, the national level.

Different manufacturers are having varying degrees of difficulty maintaining compliance with CAFE standards. Some manufacturers, particularly those marketing compact and/or subcompact models exclusively, routinely meet the 27.5 mpg CAFE new car fleet standard by a comfortable margin. In fact, some companies have experienced significant declines from their past years' CAFE levels, but still meet the standard. Other companies marketing a broader mix of models that includes large size cars, have more difficulty meeting the standard, with some complying through use of allowable prior-year or future-year credits. Still other companies who market predominately luxury model lines routinely fail to meet the standard and resort to paying the substantial fines that apply, sometimes in addition to the separate "gas guzzler" tax that applies to low mpg models.

Fuel economy label ratings for individual 1997 model vehicles range from a high of 44/49 mpg (city/highway) for the subcompact Geo Metro to a low of 9/14 mpg for the Lamborghini Diablo high performance sports car. Light-duty truck ratings range from a high of 23/30 mpg for the Chevrolet S-10 small pickup to a low of 11/15 mpg for the Dodge B-3500 van. The above fuel economy ratings are U.S. EPA "Gas Mileage Guide" estimates, also used on new vehicle window stickers, calculated by adjusting (downward) the vehicle fuel economy test results used for CAFE compliance, to better reflect on-road driving.

Availability of high fuel economy automobile models has actually diminished in recent model years, reflecting generally poor market success for these models. Discontinued models include the Honda Civic CRX (49/52 mpg), the Chevrolet Sprint (46/50 mpg) and the Daihatsu Charade (38/42 mpg). At the same time, a number of successful models have undergone substantial fuel economy improvement in the last five years.-- for example, Saturn models have improved by one to five mpg, and the Honda Accord and Geo Prizm/Toyota Corolla, have improved by one to three mpg. Some other models have held steady or slightly decreased in fuel economy, while increasing in size, weight, and/or horsepower. Light-duty truck models have mostly held steady in fuel economy, with some models improving one to two mpg, mainly in the large four-wheel drive classes.

The net result of the various changes in fuel economy of individual models, and the changing sales mix, has been a stable situation for sales-weighted new vehicle fuel economy in the 1990s, with new cars continuing to average about 28 mpg and light-duty trucks about 21 mpg. The combined car and truck average appears to be eroding somewhat, however, due to the relative increase in truck sales. Vehicle manufacturers have found it possible to comply with CAFE standards while placing new or renewed emphasis on other areas of vehicle technology that tend to be constrained by, or at least are counterproductive to, higher fuel economy requirements. Thus, today's average new vehicle, while not achieving increasing fuel economy, is somewhat larger, incorporates more safety features, has higher performance and lower emissions, and includes more comforts and accessory options than in previous model years when fuel economy increases were being implemented.

Meanwhile, the on-road vehicle population continues to improve in average fuel economy as the in-use fleet "catches up" to new vehicle fuel economy levels, although this progress is now leveling off after ten years of relatively stable new car average CAFE standards. Thus, the dampening effect that increasing fuel economy has had on highway vehicle fuel demand growth in past years is diminishing. California's annual gasoline demand, which hasn't increased since reaching its peak level in 1990, has recently shown signs of growth resumption, most likely influenced by an improving economy, more driving, increased traffic congestion, etc., but also affected somewhat by the plateau in new vehicle fuel economy. With low prevailing consumer interest in fuel economy as a vehicle purchase consideration, there is little indication that market forces will soon restore a high priority to this issue.

Legislative initiatives on behalf of higher vehicle fuel economy have not recently been in evidence. Following several unsuccessful attempts during the 1980s to enact higher CAFE standards and otherwise promote higher fuel economy, no major new proposals for further government regulatory action on fuel economy have been forthcoming. However, in a new undertaking that many see as taking the place of further federal regulatory intervention in automotive fuel economy, the U.S. Department of Energy and the "big three" U.S. auto makers have formed a joint program called the Partnership for a New Generation of Vehicles (PNGV). The ultimate goal of PNGV, initiated in 1994, is to develop vehicle technology within 10 years that will deliver similar size, cost and performance attributes to today's average automobile, but with only one-third the fuel consumption. This translates into a mid-size sedan with fuel economy of about 80 mpg, versus about 27 mpg today. PNGV also has other nearer-term goals involving advanced vehicle manufacturing technologies and interim improvements in vehicle efficiency.

The 80 mpg goal is generally recognized as extremely ambitious, and very difficult to achieve with the gasoline-fueled Otto Cycle internal combustion engine (ICE) vehicle technology being universally employed today. Much of the PNGV development activity therefore centers around hybrid electric vehicle technology -- vehicles with electric motor drive, incorporating an on-board electric generator driven by a downsized, highly efficient combustion engine. High-speed direct injection diesel engines and turbine engines are both being explored for this application. Fuel cells may offer a longer-term technology option for on-board electricity production, but probably not within the official PNGV time-frame. Vehicles with hybrid electric technologies would still carry a fuel supply on-board, with options ranging from gasoline and diesel to methanol, natural gas and even hydrogen being considered, but would theoretically attain much higher operating efficiencies which, along with advanced aerodynamics and weight reduction, could conceivably meet the PNGV challenge of literally tripling fuel economy. As described in the earlier section on electric vehicles, hybrid electric vehicle development is being pursued by each of the U.S. auto companies that are PNGV members, as well as by a number of foreign OEMs.

A technology change as fundamental as replacing ICE-powered vehicles with hybrid electric drive vehicles will, if it takes place, require many years of development and transition, with only a few experimental or concept vehicle examples of the new technology in existence thus far. Clearly, there will be more generations of vehicles incorporating continuing advances in more conventional ICE technology before any such radical changes occur. The remainder of this section provides an overview of current major directions in automotive technology development expected to contribute to increasing fuel economy. Most of these areas of technology development and application are evolving on a continuum, rather than representing revolutionary breakthroughs. Nevertheless, combinations of advances in these various technology categories hold the potential for substantial further fuel economy progress with ICE vehicles, and also stand to play an important role in achieving the more fundamental progress sought by PNGV.

A. ENGINE TECHNOLOGIES

1. Otto Cycle Engine

The predominant type of ICE used in today's light-duty vehicles is the spark-ignition piston engine operating on the four-stroke Otto Cycle. These engines are being produced for U.S. marketed light-duty vehicles with three to twelve cylinders and displacements from 61 to 488 cubic inches (1.0 to 8.0 liters). All U.S. marketed versions operate exclusively on gasoline except for a few vehicle options (discussed in the previous section on alternative fuel vehicles) being offered for natural gas, propane or alcohol fueling. Some demonstration and experimental models have been fueled with hydrogen.

After over 100 years of development, Otto Cycle engines are considered mature technology, yet continued refinements are being applied to continually improve various operating parameters, including power versus size and weight, fuel efficiency, emissions and durability. Recent improvements have also focused on improving computerized engine control functions. Peak thermal efficiency (available engine power divided by fuel energy content) being realized by this engine technology appears to be over 30 percent, although actual average operating efficiencies in typical (stop-and-go) driving cycles may be only about 20 percent. The demonstrated capability of OEM auto makers to produce gasoline-fueled Otto Cycle engine vehicles with continually lower emission levels, aided by the advent of reformulated gasoline, is sustaining the commercial dominance of this technology and (as discussed in the prior section) forestalling the need to adapt it to cleaner fuels.

The following areas of ongoing technology development and application stand to contribute further incremental improvements in Otto Cycle automotive engine efficiency, with most believed to be generally applicable to engines using gasoline or alternative fuels.

C Advanced Fuel Induction Systems

More sophisticated approaches to precisely controlling and metering fuel/air mixtures continue to be developed for improved combustion efficiency. Various types of electronic fuel injection have completely replaced the automotive carburetor in new light-duty vehicle applications. Continued advances such as variable tuned induction may contribute to even more efficient fuel mixture preparation. Ford is exploring spark ignition applications of direct injection technology, previously thought applicable only to diesel engines, as part of the company's PNGV effort, which seeks combustion engine technology exceeding 40% peak efficiency.

Mitsubishi and Toyota have also been pursuing direct injection gasoline engine development, with both companies planning to introduce models with direct injected engines in the Japanese market, where emission requirements are less constraining.

C Valvetrain Improvements

Traditional two-valve per cylinder designs (one intake and one exhaust valve) are giving way to increased numbers of valves and more sophisticated valve timing systems for more efficient processing of fuel mixtures and exhaust gases in and out of the cylinder. Four-valve designs are already incorporated in a number of engine models, and five-valve designs (with an extra intake valve) are also being used on a few models. Variable valve timing systems, which allow better optimization of valve openings and closings under different engine operating conditions, are seeing initial application. Electronic valve actuation systems, which could provide complete timing flexibility and eliminate the mechanical complexity of camshafts, timing gears, etc., are under development.

C Lean-Burn Designs

The ability to more precisely control and vary air/fuel ratios and valve operations makes it possible to use more air and less fuel under certain operating conditions. Such "lean-burn" engine operating designs have been incorporated by several Japanese companies, with some reports of up to a 20 percent improvement in fuel economy. The future proliferation of this approach in the U.S. and California remains somewhat uncertain due to effects on emissions, with progress in catalyst technology for lean operation possibly the key.

C Supercharging and Turbocharging

Increasing the pressure of the intake air above that achievable with normal atmospheric pressure can increase power output per cubic inch of engine displacement, thus allowing use of reduced displacement engines. Superchargers (driven by the engine crankshaft) and turbochargers (driven by exhaust gas flow) are seeing increasing development and application for this purpose. Most OEM companies and some component suppliers are pursuing such technologies, with various types of systems being applied on a number of available engine models. However, new federal emission certification testing requirements may be a constraint to their wide application.

C Increased Compression Ratio

Higher compression ratios correlate directly with higher engine efficiency, but have been limited by reduced gasoline octane due to the phase-out of leaded gasoline. However, some manufacturers have continued to explore technological avenues for compensating for reduced octane and restoring compression ratios closer to those previously attainable. Compression ratios of over 11:1 have reappeared in some production engines (compared with 9:1 or lower ratios commonly adopted following lead phase-out), and Volkswagen has developed a concept vehicle engine with a 16:1 compression ratio. Nevertheless, compression ratio increases remain limited by gasoline octane levels and by manufacturers' reluctance to specify higher octane premium gasoline. Alternative fuels with high octane ratings (e.g., alcohol fuels, natural gas, propane) tend to allow higher engine compression ratios.

C Friction Reduction

Reducing friction between moving engine components is a constant area of technology development aimed at lowering internal energy losses, with attendant wear reduction. Improvements currently receiving attention include low-tension piston rings and roller cam followers, which have reportedly allowed Ford to reduce engine friction of its 4.6 liter V-8 by as much as 2 percent, helping contribute to this engine's achieving a 20 pound weight saving and a measurable mpg fuel economy improvement over the 5.0 liter engine it replaced.

In addition to refinements to the traditional four cycle, piston driven engine technology such as the above examples, some more basic variations of the Otto Cycle engine have been under recent development. The most noteworthy alternative designs include:

C Two Stroke Engine

The two stroke engine, which has been a fixture in motorcycle and various implement applications, has been actively pursued for automotive applications. Two stroke engines can be lighter and more powerful, as well as more efficient, than comparable four stroke engines; however, long term durability and the ability to meet emission standards are serious concerns. New two stroke designs for automotive use have separate fuel and oil lubrication systems and other improved features that drastically lower the emissions when compared to older two stroke designs that burned a fuel/oil mixture. Direct injection is also employed to improve emissions and fuel economy. An Australian company, Orbital Engine Corp. Ltd., has led recent progress in advancing two stroke engine technology for automotive use. A number of OEM auto companies, including Ford, GM, and Volkswagen, have obtained license agreements from the Orbital Engine Company to use their two stroke Orbital Combustion Process. Other companies, including Chrysler and Toyota, have undertaken their own development of two stroke engines. Some manufacturers have displayed concept vehicles with two stroke engines and some indicated initial plans to equip production vehicles with such engines by the mid to late 1990s; however, this now appears unlikely. Although considerable progress has been made with this technology, including prototype testing by various companies and multiple-vehicle field trials, required levels of engine durability, emissions and noise have apparently not been demonstrated, causing most of the OEMs involved to scale back their two-stroke development efforts, at least for the time being. Chrysler, for example, recently disbanded its eight-year project to develop a two-stroke engine, citing concerns with lean NOx catalyst development and particulate matter standards.

C Rotary Engine

The rotary (or Wankel) engine also operates on the two stroke Otto Cycle, but uses a triangular rotor rotating within a double lobed casing instead of a piston and cylinder arrangement. Although compact and lighter than a comparable four-stroke piston engine, the rotary has not shown a significant efficiency advantage. The Wankel design is fairly mature with relatively little new research being done on this concept. This concept has been proven and until recently was available on a production automobile, the Mazda RX-7. However, Mazda has discontinued this model and other OEMs have shown little interest in the rotary engine. Other independent developers have pursued alternative rotary engine designs, including one known as the "Rand Cam," but none have attracted serious auto industry interest.

C Miller Cycle Engine

The Miller Cycle (named for the inventor, Ralph Miller) employs a technique for using cam timing to alter the effective compression ratio, allowing increased power to be obtained from smaller displacement engines. Mazda, Honda and Ford have been active in development of engine technology using this concept. Mazda is the first company to produce a commercial version of a Miller Cycle engine, available as an option in the Millennia model as of the 1995 model year.

2. Diesel Engine

The diesel engine relies on temperatures and pressures created by high compression (rather than spark plugs) for ignition. The high compression ratios (typically 16-17:1) make it one of the most thermally efficient engine types, attaining peak efficiency of over 40 percent in production engines. Using diesel fuel, which contains about 12 percent more energy per gallon than gasoline, a diesel engine vehicle can normally attain 30 percent better fuel economy than a gasoline counterpart. For heavy-duty vehicle applications, diesel engines have become predominant due to their durability, fuel economy and torque advantages. For light-duty vehicle applications, the diesel engine has had only limited success, particularly in the U.S. and California, where emission standards have posed a severe obstacle to its use. Alcohol fuel adaptations of diesel engines have been produced for heavy-duty vehicles, but not thus far for light-duty vehicles.

Diesel engine applications in light-duty vehicles appear to be making a slight resurgence in the U.S., following years of virtual absence. For the 1997 model year; Chrysler, Ford and GM all offer a diesel engine option in certain light-duty truck models and Mercedes Benz and Volkswagen both have diesel engine passenger car options. Diesel engine light-duty vehicles are experiencing much greater popularity in foreign markets, especially in European countries. Still, the future of the diesel engine in the U.S. light-duty vehicle market remains highly uncertain, especially with the advent of California's Low Emission Vehicle emission standards, and proposed federal air quality standards with tighter particulate requirements.

3. Turbine Engine

The combustion turbine (or gas turbine) engine, operating on the Brayton Cycle, is capable of peak thermal efficiencies of 40 per cent or more with energy recovery enhancements. Its successes in aviation, marine and electric power generation applications have yet to be successfully transferred to highway vehicles, despite some significant attempts at automotive development. The demanding duty cycle requirements of motor vehicles, together with emission regulations, packaging difficulties and cost issues have combined to keep the turbine from achieving its high-efficiency potential as a ground vehicle engine, except for limited military (Army tank) applications.

GM and Chrysler both pursued the turbine engine option for a number of years, displaying several turbine engine concept vehicles. The United States Department of Energy, and two private companies, Allison and Garret, have developed prototype high-temperature ceramic turbine technology for vehicular use. Turbine automotive engine development has also taken place in Japan, with involvement by Toyota, Mitsubishi and NGK. None of these efforts have produced results that appear to be leading toward a production highway vehicle with turbine engine propulsion.

The emergence of hybrid electric vehicle technology development includes a newly explored role for turbine engines to power on-board electric generators, and is prompting new turbine development activity aimed at this application. The PNGV program is considering turbines for this purpose, and both GM and Chrysler have built hybrid EV concept vehicles with turbine-powered generators.

B. DRIVETRAIN TECHNOLOGIES

1. Advanced Manual Transmissions

The manual transmission has, in general, proven to be most efficient due to its direct mechanical gearing, as opposed to the viscous coupling of automatic transmissions. Advanced manual transmission design efforts focus on improving the overall engine operating efficiency by increasing the number of gears and also by combining a manual four-speed transmission with an automatic fifth gear in a semi-automatic mode. Increasing the number of available gears from three or four, as standard on past vehicles, to five or even six or seven gears will allow the engine to operate at more optimum speeds for fuel consumption. This increases the mechanical efficiency of the system and reduces fuel consumption. Ford is developing a 6 speed manual transmission for some models, as well as a 7 speed manual transmission with potentially semi-automatic operation, currently intended only for racing applications. Higher numbers of gears are unlikely, due to increasing mechanical complexity, consumer acceptance issues, and diminishing efficiency returns.

VW and Renault have found that most drivers of vehicles equipped with fifth gear (manual) overdrive do not make optimum use of the fifth gear. A prototype manual transmission, in which the first four gears are shifted manually while the fifth gear shift is performed automatically, reduced highway fuel consumption by five percent. These manufacturers have not yet marketed this technology due the added costs of these new transmissions.

Manual transmissions have diminished in popularity, accounting for under 30 percent of light-duty vehicle sales in the U.S. as of the 1995 model year. Many models are now available only with automatic transmissions.

2. Advanced Automatic Transmission

Automatic transmissions use a torque converter with a viscous liquid coupling to supply engine power to the gearing. Conventional automatic transmissions select the proper gearing based on vehicle speed and engine load. Advances in automatic transmission technology include lock-up torque converters, electronic transmission controls, increased number of gears and automatic/manual hybrids. The efficiency gap between manual and automatic transmissions has narrowed considerably due to such improvements, with some models' tested fuel economy only 1 mpg lower with an automatic transmission. Electronic automatic transmission controls are being incorporated by a number of manufacturers' production vehicles. The development of automatic five and six speed transmissions is currently underway with five speeds making a recent limited appearance on the market. Examples of advanced automatic transmission development include the "Antonov Transmission," being tested by several Japanese and German auto companies, and the Porsche "Tiptronic" transmission, both incorporating advanced efficiency-improving designs.

3. Continuously Variable Transmission

The continuously variable transmission, versions of which have appeared for many years in applications such as snowmobiles and golf carts, has had limited success breaking into the realm of automotive technology. The basic advantage of the CVT involves a continuous range of gear ratios between the engine and the driveshaft. This allows the engine to be run at its most efficient operating point for a given driving condition and load. CVTs are also usually automatically controlled and do not require driver input for the selection of proper gear ratios. CVT designs thus far have incorporated a belt and pulley system that has limited applications to smaller (i.e., 2 liter) engines. Other design variations intended to have higher power transfer capability, including traction drive and hard-geared systems, as well as more advanced belt-and-pulley systems, are under development.

CVTs have thus far appeared in only two vehicle models sold in the U.S., the discontinued Subaru Justy and, more recently, the Honda Civic HX, which exhibits both increased fuel economy and performance. Several other manufacturers have produced CVT-equipped models for the European and Japanese markets. CVT model test results in Europe have shown a 12 percent improvement in city fuel economy and a 7 percent highway improvement, although the Suburu Justy CVT model exhibited slightly lower fuel economy than its manual transmission counterpart. Hyundai Motor Company is the most recent OEM to develop and test a CVT, which is said to offer a potential 10 percent fuel economy gain on the 1.4 liter Accent model if made available.

4. Regenerative Braking

Conventional braking systems convert the kinetic energy of a vehicle's motion into heat which is wasted into the environment. Regenerative braking systems recover part of this energy loss for subsequent propulsion. This type of technology is most effective in urban use where continuous stop and start driving is experienced. The most successful type of regenerative braking technology applied to ICE vehicles has been a hydraulic accumulator system, in which recovered braking energy is stored and reapplied to the drivetrain by hydraulic pressure. Systems tested in Europe on heavy-duty buses and trucks showed substantial (i.e. 20 to 30 percent) fuel-savings, but adaptation or testing of similar systems on light-duty vehicles is not known to have occurred. Flywheel energy storage has been less successfully used for regenerative braking systems.

The current focus of regenerative braking technology is on electric vehicles, where recovery and reuse of braking energy is easily accomplished with electric motor/generator systems. Most state-of-the-art EV designs incorporate regenerative braking technology. The additional cost and complexity of regenerative braking systems on ICE vehicles limits current auto industry interest in such applications.

5. Stop-Start Systems

Stop-start systems shut off the vehicle's engine at times when it is not under load, thus reducing energy use and emissions resulting from idling and coastdown modes. Some stop-start system designs incorporate flywheel energy storage for power assist when the engine is off and to replace the engine braking effect. Several OEM companies have engaged in stop-start system development, most notably Volkswagen, which has conducted prototype vehicle testing with such systems in Europe. However, problems with customer acceptance and emission control persist, and there are no known plans for production applications.

6. Tire Technology

One third of the energy delivered to a vehicle's wheels is, on average, consumed in overcoming rolling resistance. Rolling resistance is a function of the vehicle's weight, the road surface and tire design. A ten percent improvement in rolling resistance has been estimated to result in an approximate two percent improvement in fuel economy, although this is subject to diminishing returns as gains continue to be made. Advanced tire designs focus on advanced tread design, material composition and weight reduction. Decreases in tire contact area or increases in tire operating pressures can also reduce rolling resistance, but may adversely affect safety characteristics (such as braking and handling performance, failure resistance, etc.) and ride comfort.

The older bias-ply tire has largely been replaced by the more efficient radial tire, a transition that was nearly complete by 1990. Further efforts to develop more advanced tires continue in the competitive tire industry, spurred by inter-industry competition, safety objectives, racing and on-road performance and fuel economy factors. For example, Goodyear Tire and Rubber Company has developed the Invecta greater fuel economy (GFE) tire using advanced rubber chemistry to achieve a 20 percent reduction in rolling resistance over its other aftermarket tires. Goodyear also developed a tire named the G-22 especially for the GM EV1 electric vehicle, which is 50 percent lighter than conventional tires and has 45 percent less rolling resistance. Michelin has developed a new tire compound called XSE, said to offer a 35 percent improvement in rolling resistance versus other aftermarket tires. The DuPont

Company also claims that the replacement of steel in radial tires with aromatic polyamides can reduce tire weights by 5 percent. DuPont's product, a Hyten monofilament fiber, is being investigated by several major tire manufacturers.

Another fuel economy-related tire development involves puncture-proof and run-flat tires, invented partly for the purpose of eliminating the need for a spare tire and jack for weight reduction and customer safety reasons. Some higher-price vehicle models now incorporate such tires, and eventually all models may have this technology.

C. AERODYNAMIC TECHNOLOGY

Aerodynamic drag is defined as the force of the air resisting the vehicle's motion. This resistive force is a function of the vehicle's overall shape (termed the coefficient of drag, commonly written as Cd), the frontal area of the vehicle, the density of the air and the speed of the vehicle. Reducing frontal area is limited by the vehicle type, safety design, physical requirements of the occupants, packaging of the power plant, etc.; therefore, the reduction of aerodynamic drag has been pursued mostly through optimizing the design of the vehicle for reduced Cd. It has been estimated that a 10 percent reduction in Cd can lead to a 5 - 6 percent improvement in fuel economy at highway speeds and a 1 - 2 percent improvement at urban speeds. In addition to being a major strategy for improving fuel economy, aerodynamic design improvement contributes to better vehicle stability and handling characteristics at higher speeds, as well as noise reduction.

The range of Cd values can be generally represented by a flat plate, with a Cd of 1.15, and a perfect tear-drop shape (blunt end forward), with a Cd of 0.05. Early model cars of the 1920s commonly had a Cd of 1.0 or more, but by the 1970s, Cd values had progressed to an average of 0.48 for American cars and 0.44 for European cars, with the advent of wind tunnel testing to help quantify the results of modifications. Many of today's production vehicles are in the 0.35 to 0.30 range, with a few models as low as 0.25, now aided by computerized design techniques. Various concept vehicles have been built with Cd values under 0.20, with the Ford Probe V concept automobile, shown in the 1980s, still one of the lowest at 0.137.

Among the extensive array of vehicle design and engineering options used to reduce aerodynamic drag are the following examples:

- Rounding and shaping vehicle corners and surfaces for optimum airflow
- Use of spoilers under the front and rear bumpers, and at the trailing edge of the body
- Fender flaring to reduce tire and wheel well drag
- Use of flush-mounted glass against the body and shallow windshield angles
- Low sloping hoods and aerodynamic headlamps

- Advanced engine cooling schemes that minimize drag associated with air intake and outlet openings

- Reduced surface protrusions such as door handles, mirrors, roof drip rails, window moldings, radio antennas, chrome trim, emblems, etc.

- Flush wheel covers and fender skirts

- Covering of underbody openings to reduce turbulent airflow due to cavities

- Active suspension systems which modify vehicle ride height for varying speed and road conditions

Obviously, many of the easiest drag-reducing approaches have by now been heavily exploited. Nevertheless, refinements continue to be made in a wide variety of areas such as those noted above, resulting in incremental Cd reductions on most models. Major new changes that would reduce Cd values to the lowest concept vehicle levels face certain practical limitations. For example, underbody enclosures offer a remaining area with significant drag-reducing potential, but are limited by maintenance and heat-rejection requirements. Vehicle safety requirements add a further constraint to aerodynamic design. The increasing popularity of light-duty truck and van models poses a further challenge for aerodynamic technology progress, since the utility function of these types of vehicles serves to constrain application of some of the aerodynamics approaches used on automobiles.

D. MATERIALS TECHNOLOGIES

Development of lighter weight automotive materials applications is one of the major areas of emphasis of every auto manufacturer and component supplier, and a key objective of the PNGV program as well. Since a 10 percent reduction in vehicle weight can result in a 3 percent to 4 percent improvement in fuel economy, efforts to trim weight focus on nearly every automotive component. With the addition of new safety-related systems, such as anti-lock brakes, air bags, structural support members, etc., as well as the resurgent popularity of somewhat larger size models and addition of more accessory and comfort features, use of lighter materials has been an important compensating strategy to maintain CAFE levels. Today's average new automobile is over 800 pounds lighter than the average 1975 car, partly due to lighter materials and partly due to downsizing, and further weight reduction is expected. Light-duty trucks have not yet undergone as much weight reduction as passenger cars, but are beginning to receive more weight reduction emphasis, while maintaining primary emphasis on vehicle utility.

Materials receiving most attention for lighter weight automotive component development include aluminum, magnesium, steel, plastics and composites, and ceramics. A brief review of each of these materials' development status follows:

1. Aluminum

Aluminum, which has one-half the density of steel, has seen a major increase in its automotive applications in recent years and appears likely to see expanded usage. Major current production vehicle applications of aluminum are in the engine compartment, with numerous models now incorporating aluminum engine blocks and/or cylinder heads, along with aluminum pistons, which have become increasingly common. Other applications where aluminum is making major automotive inroads are replacing steel in wheels, and as a substitute for copper in radiators.

New applications of aluminum as a body material are also emerging, with some U.S. production models using hoods, deck lids and other individual body parts made of aluminum. The first all-aluminum body vehicles (in recent times) have been introduced by Japanese and German companies in the form of two limited production models, the Acura NSX in 1990 and the Audi A8 in 1994, which also use aluminum as the frame material. The first U.S. produced all-aluminum body vehicle is Chrysler's Plymouth Prowler, a limited production roadster being introduced for the 1997 model year, and a test bed for lightweight material applications. Almost one-third of the Prowler's weight will be comprised of aluminum components, including its frame, bumpers, brake rotors and certain suspension parts. GM's electric EV-1 also incorporates major aluminum components.

Ford, which has been a pioneer in the use of aluminum components, is conducting a field test in Canada with a fleet of aluminum-bodied Tauruses, which weigh 400 pounds less than the standard steel model. While new applications of aluminum as a component material continue to be explored, and more limited production aluminum-intensive vehicles are anticipated, mass produced all-aluminum vehicles are not currently planned because of remaining cost, manufacturing and repair issues with this material.

2. Magnesium

Magnesium, weighing one-third less than aluminum, is also seeing increasing application as an automotive component material, although not in any current applications as large as its previous use by Volkswagen for engine blocks. Its higher price tends to limit consideration of magnesium for major engine, body or chassis components such as those being pursued with aluminum. Magnesium is finding its way into a number of smaller component applications where its easy formability and strength, in addition to its light weight, are advantageous. Current examples of magnesium components appearing on various makes and models include valve covers, seat frames, wheels, pedal support brackets, instrument panel support beams and various accessory brackets. The high cost and limited resource availability of magnesium will probably limit future expansion of its automotive application to such specialized components.

3. Steel

In the face of intense competition from aluminum and plastics/composites, the steel industry is making a major effort to retain its automotive markets by developing new lighter weight component products. While the cast iron and zinc content of the average vehicle has dropped substantially, the contribution of steel -- in its many forms, including galvanized, forged, hot-rolled, bar, tubing, rod, stainless and wire -- has diminished only slightly. Continuing product improvements, along with its low-cost, strength, formability and recyclability, are keeping steel a primary material for automotive production. Advances such as high-strength, low-alloy steels, hydro-formed tubing, laser welding, steel-faced honeycombs, bake-hardenable steel and others promise to maintain steel as a viable competitor for major automotive components for some time to come. The International Iron and Steel Institute has initiated a worldwide consortium to develop the "lightest-possible" steel-bodied passenger car, and the steel industry has indicated its intentions to the PNGV program to make advanced developments with steel consistent with the program's objectives.

4. Plastics and Composites

Advanced plastic materials, including unreinforced types used for non load-bearing components as well as fiber-reinforced types and carbon fiber composites, are finding increasing automotive applications. Fiberglass has seen limited use, such as on the Chevrolet Corvette, since the 1950s. Some of the most significant materials developments of late involve use of plastics for body panels. Although GM's initial application of plastic body panels on its 1990 minivans has been discontinued, a number of current production models incorporate various vertical (fenders, doors) and horizontal (hoods, deck lids) panels made of sheet molding composite or other type of plastic material. Front and rear fascias made of plastic materials are also becoming increasingly common, as are grills and trim components.

Plastics are also beginning to be used for certain underhood components, with the development of new heat-resistant thermoset and thermoplastic materials. Plastic intake manifolds are now used on some production models, as are plastic valve covers, fuel rails, throttle bodies and air intakes. Experimental applications of plastic materials have extended to a number of basic engine components, including the engine block, cylinder heads and camshaft, indicating future expanded potential for plastics in the engine compartment.

Other automotive applications of plastics being introduced or under development include certain structural components such as leaf springs, bumper beams and radiator support brackets. Also, new vapor-impervious plastic materials are prompting resurgent interest in plastic fuel tanks. Plastic composite wheels have also been initially employed on some production vehicles. Recycling issues are a remaining issue receiving considerable research related to wider use of automotive plastics.

Carbon fiber composite materials are extremely light and strong, resulting in their use in the aircraft industry and their wide adoption for race car bodies. However, the high cost of carbon fiber limits consideration of its use in mass produced vehicles, except for a few specialized applications. GM, for example, is using carbon fiber driveshafts on some models, said to result in a 20 pound savings over conventional steel driveshafts. Other individual carbon fiber automotive components, including wheels, have been developed and tested by various OEM and supplier companies. GM has also displayed a high fuel economy concept car, the Ultralite, which featured a completely carbon fiber composite body, but cost and manufacturing issues make the timetable for potential use of this material for production automotive body components highly uncertain.

5. Ceramics

Ceramics are an attractive engine material for designers due to high strength-to-weight ratios, heat-rejection capacity and wear resistance. The main uses of ceramics to date in production vehicles have been for turbocharger components, with both Nissan and Porsche applying ceramic materials on their turbocharged vehicles to improve turbocharger response, efficiency and heat transfer. Other ceramic engine components such as valves and piston pins have been subjects of development activity, but have not reached the commercial production stage. Several foreign manufacturers, including Opel and Isuzu, have pursued development of even more extensive use of ceramics as an engine material. However, durability concerns with this inherently brittle material continue to forestall any production plans for ceramics-intensive engines.

E. ACCESSORY TECHNOLOGIES

Power accessories such as the alternator, air conditioning (A/C), steering pump, fan, oil pump, and other devices can consume from 2 percent to 8 percent of the engines's shaft energy. Manufacturers are investigating methods of either boosting the efficiency of these devices, reducing their parasitic losses, or reducing their operating requirements. Several new ancillary automotive technologies offer the potential for energy savings as an associated benefit of their operation. Brief summaries of some significant examples of technology development in this area follow:

1. Air Conditioning

The air conditioning unit is the largest consumer of shaft energy of all the accessories, consuming up to five horsepower. Most new vehicles sold in California now include A/C. Older A/C systems were oversized for instantaneous cooling, whereas current A/C systems are smaller in capacity and operate intermittently, decreasing the load on the engine. Toyota and GM have developed variable displacement compressors that reduce power consumption by up to 30 percent. Zeolite air dryers can be used in A/C systems to lower humidity and reduce energy consumption.

The worldwide switch to non-chlorofluorocarbon refrigerants represents a setback to the improvement of auto A/C efficiency, since the replacement refrigerants operate at lower efficiencies than the traditional fluorocarbon refrigerant. However, efforts to compensate for this change are ongoing. For example, an aftermarket manufacturer, Rovac of Massachusetts, has developed a rotary vane compressor for use with the new refrigerants, which is said to be 5 percent more efficient than conventional compressors using these refrigerants.

Current development interest in electric vehicles, which lack engine belt-driven power for A/C compressors, is prompting development of electrically powered auto A/C systems, some using heat pump type technology. Internal combustion engine vehicles may ultimately benefit from this development also.

2. Alternator

The alternator converts shaft power into electricity to recharge the battery and power the electrical system. Typical units consume 1 to 2 shaft horsepower. Honda has developed a unit which uses the power that is wasted when the vehicle is decelerating or at idle by maximizing the system charging at those times. Honda claims that at highway speeds this alternator can improve fuel economy by .73 percent to 3 percent.

3. Power Steering

Power steering consumes approximately 1 horsepower and has the most effect at lower speeds, while at highway speeds its function is largely unnecessary. Auto manufacturers are investigating means of improving the mechanical efficiency of the power steering pump and varying the output of the pump for particular driving conditions. Also under development, again partly due to electric vehicle requirements, are electric power steering systems, which may prove to be advantageous for ICE vehicle applications as well.

4. Solar Assist Devices

Solar cells can be used to provide additional electricity to power accessories, recharge the battery, or to otherwise reduce the load on the vehicle's electrical system. Mazda introduced a solar assist device in its 929 model in the 1992 model year, using solar cells to generate electricity which powers a fan that ventilates heat from the vehicle's interior. This system is activated when interior temperatures reach a preset level. The solar cells can produce up to 11 Watts on a sunny day and can reduce interior temperatures from 160 degrees Fahrenheit to 122 degrees Fahrenheit, reducing the A/C load and reducing the time to reach 77 degrees by 30 percent. On cool days when ventilation is unnecessary, the generated electricity can be used to recharge the car battery. The system can fully recharge a battery at 70 percent capacity in five sunny winter days.

5. Heat Battery

This technology consists of a heat storage unit which stores waste heat from the engine. During a cold start, the device cycles the cold engine coolant through the heat storage unit and back into the engine, preheating the engine. This system reduces the high fuel consumption and high emissions associated with starting a cold engine conventionally.

Initial fuel consumption testing by U.S. EPA of a heat battery system developed by Schatz Thermo Engineering of Germany showed a 14 percent fuel economy increase during the vehicle warm-up phase and a 2.4 percent improvement on the entire driving cycle. The first commercial version of this system will soon be available as an option on certain luxury models from German manufacturers.

F. CHALLENGES FOR FURTHER DEVELOPMENT

As described in this section, progress in development of technologies that can improve automotive fuel economy continues to be made, although average fuel economy of new vehicles sold in the U.S. has remained stable for several years. The following general factors appear to be working to limit any further increase in fuel economy of the new vehicle fleet at the present time:

1. Technology Cost

Few remaining fuel economy-improving technology options can be implemented at a cost savings or at no extra production cost. Past gains in fuel economy heavily exploited those technology areas with the greatest cost-effectiveness. Auto manufacturers are currently attempting to hold the line on increasing new vehicle purchase prices, while complying with mandated safety and emission improvements. Meanwhile, low fuel prices make it difficult to justify the extra cost of fuel saving technology to the consumer. Thus, unless a technology change is necessary to maintain CAFE compliance, or offers other benefits such as a reduction in material or manufacturing costs, auto companies are not currently motivated to invest in fuel economy improvements.

2. Lack Of Consumer Priority

A protracted period of affordable and plentiful fuel supplies has eroded the importance of fuel economy as a vehicle purchase consideration, with fuel cost representing a diminishing component of overall vehicle ownership and operating costs. Consumer surveys consistently list purchase price, safety features, performance, and comfort and amenity attributes as more influential factors in vehicle purchase decisions, a major change from past times when fuel economy occupied a much higher priority. In addition to reducing market demand (and willingness to pay) for fuel economy-improving technologies, this is also contributing to the lower market popularity of high fuel economy models and increasing sales of light-duty trucks and vans.

3. Reduced Regulatory Pressure

Reaching the peak levels of CAFE standards, originally established by Congress in 1975, has stabilized the pressure that previously existed for continuing gains in average new vehicle fuel economy from one model year to the next. While maintaining compliance with the prevailing standard still requires a measure of continuing efficiency progress (to offset the changing model sales mix, compensate for safety features and emission controls, increase performance, etc.), there is little motivation to deliver fuel economy progress beyond the level of the prevailing standards. Meanwhile, initiatives by some individual states to adopt measures aimed at improving vehicle fuel economy have been shelved, at least partly due to the recognition of federal government preemptive authority in this area.

4. Technical Issues

The fuel economy-improving potential of many types of advanced technologies continues to be constrained by various technical obstacles to production applications, irrespective of the other impediments noted above. The most significant issue categories include:

- Emission Requirements

  Progressively lower emission standards pose increasing difficulty for use of some technologies, including examples as varied as the two-stroke engine, turbocharging, lean burn engines, and manual transmissions.

- Safety Requirements

  Increasing vehicle safety standards covering many areas such as bumpers, lighting, handling, vision, etc., as well as occupant crash protection, also tend to work counter to the incorporation of some types of fuel economy improving technologies, most notably use of materials with less structural integrity than steel.

- Manufacturing Problems

  In an age of increasing sensitivity to manufacturing cost control, including more mechanized production processes, switching from proven technologies to those that pose new production process difficulties meets extra resistance. Prime examples involve the use of new materials whose other advantages may be offset by their lack of adaptability to common mass-production component manufacturing processes.

- Reliability, Durability and Serviceability Concerns

  With new vehicles achieving marked improvements in reliability, durability and service requirements, manufacturers are especially reluctant to risk any compromises in these highly competitive areas. Thus, some new fuel economy technologies may find their path to commercial introduction slowed by unresolved product quality issues.