6. Research Needs for Alternative-Fuel Vehicles

To be successful in the transportation market, alternative-fuel vehicles (AFV's) must meet a number of performance and cost requirements. Ideally, AFV replacements for conventional vehicles would have superior attributes and be lower in cost and, thus, would be eagerly accepted by businesses and consumers. In fact, each AFV technology has one or more shortcomings relative to conventional vehicles. Furthermore, conventional vehicle technology continues to be improved, despite nearly a century of refinement. As a result, there continues to be a need for research, development, and demonstration of AFV technology. This chapter reviews the status of AFV technology, the important considerations that will bear on its success in the marketplace, and summarizes the key areas where further research could significantly improve the chances of success for AFV's.

There are several requirements that must be met before a new fuel may be commercialized (Ecklund, 1986). These are as follows:

- The fuel-vehicle system must perform comparably to existing systems.
- The fuel must be readily available.
- Costs must be competitive.

Even with assistance from national policies, the stakes of AFV technology must be such as to ensure that performance and economics are satisfactory. Although problems may still exist in overcoming institutional barriers, including startup costs, large investments, and user reluctance to change, these can be attacked in reasonable fashion, providing the basic outlook is positive. Before pinpointing research needs, it is important to understand where AFV's fall short of the performance available from existing technology.

6.1 Status of Alternative-Fuel Vehicle Technology

The major options for use of alternative fuels in highway vehicles are identified in Tables 23 and 24 for spark-ignition engines, as are typically used in passenger vehicles and light-duty trucks, and for compression-ignition (diesel) engines used in heavier trucks and buses (Ecklund, 1986, Bechtold, 1988, and EA-Mueller, 1989).

Electric vehicles provide a third and entirely different option. These tables also note in simplified fashion the ease of adapting present systems and the general impact on vehicle performance. Because there is a large variety of vehicle types in both categories, Table 25 notes the general applicability of these fuel options, and further notes the nature of the fuel or energy storage. The information provided includes synthetic fuels (from oil shale and coal) and hydrogen to provide greater perspective for those options on which the committee has focused.

Basic technology is not a significant deterrent to use of alternative fuels (Ecklund, 1986). Table 26 indicates technology availability, showing that with the exception of the fuel cell for electric power, the essential technologies are available. In addition, development of experimental vehicle systems has progressed to a reasonable degree except for applications of hydrogen and fuel cells, which are typically classed as very long-term options. The area in which significant differences exist among the options is in design of experimental and preproduction systems. This reflects a combination of technical limitations, related performance deficiencies, and resulting lack of activity by established vehicle original equipment manufacturers (OEM's).

In moving fuels and propulsion technology from curiosities to practicality, there are several well-defined steps that must be traversed (AMFUP, 1985). These are described in Figures 8 through 10. These illustrate the general status of resolving basic technology for use of the various fuel

Table 23. Alternative-Fuel Options for Spark-Ignition Engines

(dedicated systems; gasoline reference)

Fuel	Engine Adaptability	Fuel-System Adaptability	Performance and Operation
Syn Gasoline/Diesel	None required	None required	Same
Alcohols	Same techniques Many material changes	Same techniques Many material changes Larger tank	More torque acceleration, power More fuel economy Range may be less
LP Gas	Same techniques Added fuel prep	Cylindrical tank	Comparable
Natural Gas (methane)	Same techniques Added fuel prep	Large cylindrical tanks	Comparable with total system changes[a] Limited auto range
Hydrogen	Some added techniques Added fuel prep	Special tanks Exhaust heat recovery	Less power, acceleration even with larger engine[b] Comparable range

[a] Larger high-compression engine, different rear-end, greater suspension.

[b] Also need greater suspension; heavy, bulky fuel storage comparable to electric vehicle.

Table 24. Alternative-Fuel Options for Compression-Ignition Engines

(dedicated systems; diesel reference)

Fuel	Engine Adaptability	Fuel-System Adaptability	Performance and Operation
Syn Gasoline[a]/Diesel	None required	None required	Same
Alcohols	Same ignition source[b] Many material changes	Same techniques Many material changes Larger tank	Comparable power Less fuel economy Range may be less
LP Gas	Need spark ignition Added fuel prep	Cylindrical tank	Comparable
Natural Gas (methane)	Need spark ignition Added fuel prep New design strategy	Large cylindrical tanks	Comparable with total system changes[a] Sacrifice payload
Hydrogen	Need spark ignition Added fuel prep Injection at high pressure	Special tanks Exhaust heat recovery	Less power, acceleration even with larger engine[c] Sacrifice payload[c]

[a] Only fuel for diesel engine that has the required ignition characteristics.

[b] Ignition options are very high compression, bifuel (DF and alternative) via dual-injection systems and/or fumigation, added spark-ignition system, or use of cetane-improver fuel additive.

[c] Too little work done to determine that diesel adaptation is practical.

Table 25. Applicability of Alternative-Fuel Options to Vehicle Types

Vehicle	Fuel (Energy) Type and Storage Form					
	LPC (liquid)	NG (cmprs gas)	Hydrogen (hydride)	Methanol (liquid)	Electric: Battery	Electric: Fuel Cell
Light duty						
Autos						
Compact	x			x		
Standard	x	x[a]		x		
Luxury	x	x[a]		x		
Sports				x		
Van	x	x[a]	x	x	x[a]	x[a]
Pickups						
Mini	x	x[a]		x	x[a]	x[a]
Standard	x	x[a]	x	x	x[a]	x[a]
Large	x	x[b]	x	x		
Heavy duty						
Small	x	x		x		
Medium	x	x	x	x		
Semi				x		
Bus	x	x	x	x		

[a] For local delivery and trades.

[b] Depends on payload sacrifice.

Table 26. Availability of Utilization Technology

Fuel	Vehicle Application: Fundamentals	Vehicle Application: Development	Vehicle Application: Design	Fuel: Maintenance	Fuel: Handling
LP Gas	Available	Available	Available	Available	Available
NG	Available	Available	Limited	Limited	Available
Hydrogen	Available	Limited	None	None	Limited[a]
Methanol[b]	Available	Available	In practice	Limited	Limited[a]
Electric vehicle	Available	In practice	Infancy	Limited	Limited[a]
Fuel cell	In process	Premature	None	None	None

[a] For vehicle propulsion use

[b] And/or ethanol

Figure 8. Development Status of Compression-Ignition Engines Using Alternative Fuels

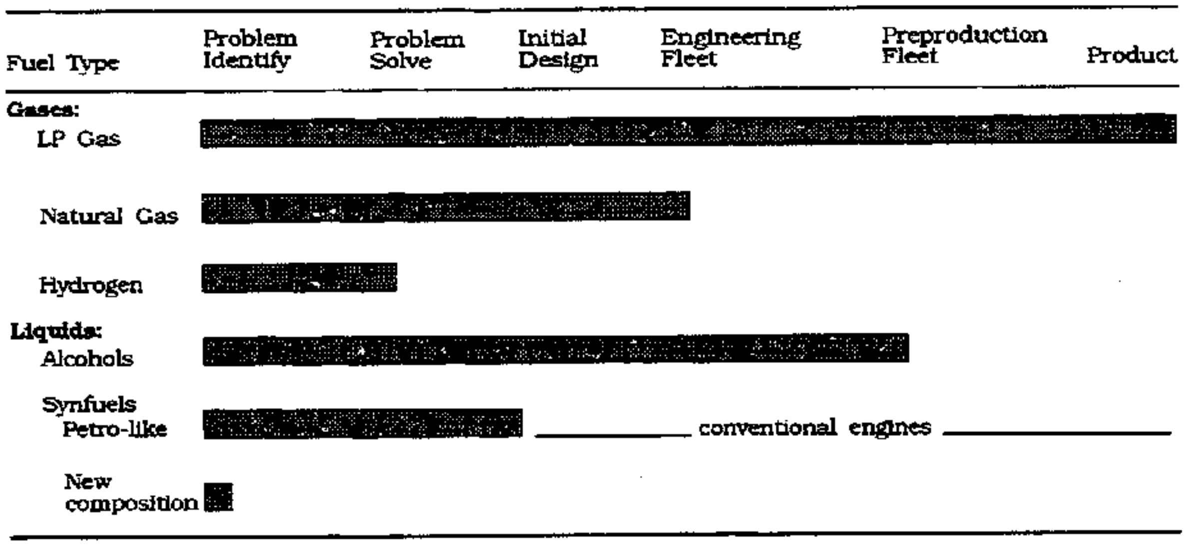


Figure 9. Development Status of Spark-Ignition Engines Using Alternative Fuels

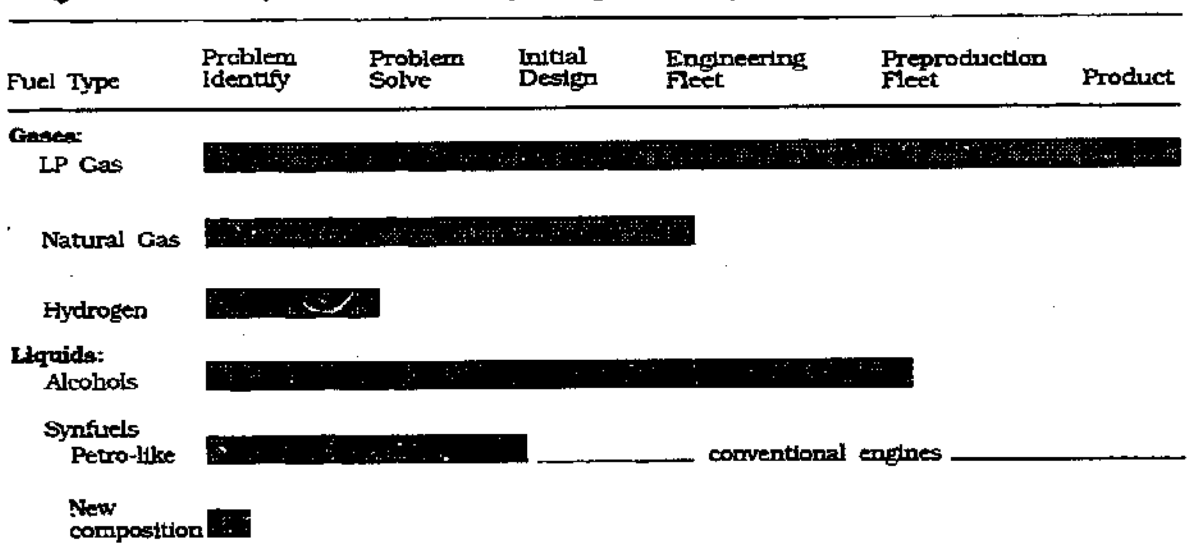
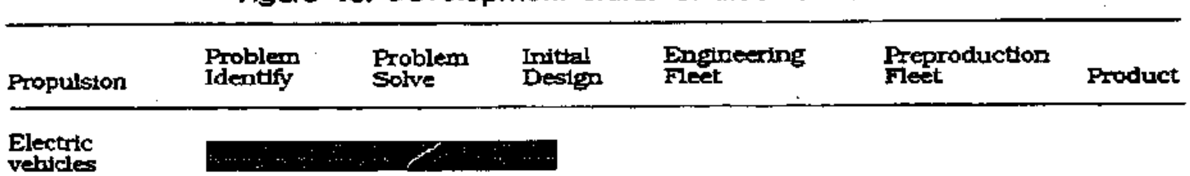


Figure 10. Development Status of Electric Vehicles



options in spark- and compression-ignition engines and in electric vehicles (EV's), as those technologies evolve through the steps of identifying problems, solving these, applying the results to an initial engineering experimental design, building up to engineering fleet work, then demonstration fleets of preproduction vehicles, and finally commercial products. Figures 8 and 9 show that LP Gas has been commercialized, but this has been only in dual-fuel designs using OEM modification following production as a conventional vehicle (Assessment of Costs and Benefits, 1988). Synthetic fuels (syn fuels) from oil shale and coal are included in these charts for comparison. These fuels typically emulate conventional gasoline and diesel fuel, and have been shown to perform just like the petroleum fuels when used in conventional engines (Swain, 1987 and Ricardo, 1980). Some very limited research and development (R&D) has been conducted on new fuel compositions from syncrudes, with a view toward reduced processing, cost, and undesirable emissions.

Among the more challenging technical problems facing AFV's are inherent difficulties in the use of fuels in a gaseous rather than a liquid state (EA-Mueller, 1988). Many of these difficulties stem from the underdeveloped state of gaseous-fuel vehicle technology. For example, the primary benefits of gaseous hydrocarbon fuels, namely low emissions, have long been touted on the basis of their inherent characteristics without qualification of application effects. However, much of the emissions technology that has been developed in the last two decades has been designed for use with liquid petroleum fuels systems. Thus, petroleum fuel systems using state-of-the-art emissions technology provide some results that are superior to those achievable with presently practiced natural gas engine technology.

Features of fuels affecting vehicle operation are listed in Table 27 (Henein, 1982). The physical state of the fuel and chemical characteristics relate to energy density, which is a major factor in vehicle operation. Typical storage techniques for various alternative fuels are compared in Table 28 (Assessment of Costs and Benefits, 1988, Brusaglino, 1991, and Office of Technology Assessment, 1990). Petroleum products have excellent energy density, yielding associated benefits that motorists have long accepted as highly desirable. Poor energy density is translated into deteriorated vehicle range, unless ways can be found to increase the amount of fuel (energy) storage. The relative energy densities of various alternative-energy sources are provided in Table 29 (Stephenson, 1990, Aerospace Corporation, 1985, and Gas Research Institute, 1990). Low-energy density is significant in use of natural gas and battery EV's. Potential solutions exist; however, a variety of approaches that have been used for various gaseous hydrocarbon fuel options are shown in Table 30 (Bechtold, 1988, and EA-Mueller, 1988). The prevalent approach for natural gas is compression, called compressed natural gas (CNG).

Another difficulty facing alternative-fuel technologists is availability of engines and vehicles that are adapted to the rates AFV's are likely to perform. In part, this is because available test devices are those designed and optimized for use of petroleum products, and modification or adaptation can be quite expensive. Furthermore, vehicles aimed at experimental or commercial use are usually after-market conversions that do not perform optimally on the alternative fuel being used. Nearly all vehicles currently operating on natural gas, for example, are of a dual-fuel variety in which the operator can select use of either that fuel or gasoline. To provide satisfactory operation on both, performance is sacrificed on both, but particularly on CNG. A method of partially overcoming this obstacle is the unique approach used with alcohol-gasoline vehicles, in which a special sensor enables designers to build a system that uses either fuel to the optimum possible given the design of the engine itself. Yet even this flexible- or variable-fuel vehicle (FFV or VFV) technology is suboptimal, because the engine design must be a compromise between what would have been optional for each individual fuel. The flexible-variable fuel approach currently applicable to liquid (that is, alcohol) fuels permits the greater benefits from the fuel and engine used, whereas the dual-fuel approach used with gases results in considerably less than optimum performance. Table 31 gives an overview of the options available in such transitional vehicles (OTA, 1990, and Bechtold, 1988).

Table 27. Fuel Features and Related Operational Characteristics

Engine Related	Fuel Storage and Handling
Octane	Energy density
Compression ratio/ efficiency	Operating range
Molecular weight	Physical characteristics
Particulate emissions	Containment shape, weight, and volume
Hydrocarbon emissions species	Physical state
Combustion charge density (volumetric efficiency)	Transfer system (open, closed)
Power and acceleration	Mixture preparation
Drivability	
Efficiency	
Fuel economy	

6.2 Considerations for Market Acceptance

What appears to be the best opportunities for application to specific vehicle types are noted in Table 32 (ORTECH and SAE). Here, the possibilities for use of pioneer vehicles in niche markets or broad AFV use become more apparent. This leads to a list of candidate first-generation vehicles that might be produced by vehicle OEM's, called out in Table 33. If vehicle designs consisted of stock engines or vehicles adapted to a particular alternative fuel, the characteristics of these vehicles, including performance, emis-

Table 28. Fuel Physical State as Used in Highway Vehicles

	Storage				Combustion Preparation	
Fuel/Form	Transfer	Pressure	Temperature	State	State	Pressure
Methane/CNG	Sealed	High	Ambient	Gas	Gas	Low
Methane/LNG	Sealed	Low	Cold	Liquid	Gas	Low
LP Gas	Sealed	Low	Ambient	Liquid	Gas	Low
Methanol	Unsealed	Atmosph	Ambient	Liquid	Vapor	Aspirated*
Ethanol	Unsealed	Atmosph	Ambient	Liquid	Vapor	Aspirated*
Gasoline	Unsealed	Atmosph	Ambient	Liquid	Vapor	Aspirated*
Diesel	Unsealed	Atmosph	Ambient	Liquid	Vapor	Moderate

* Drawn in by vacuum.

Table 29. Relative Energy Density of Fuel Options and Effect on Vehicle Storage

		20-Gallon-Gasoline Equivalent			
Fuel	Relative Energy Density	Volume (gal)	Weight (lb) Energy	Tank	Total
Gasoline	1.00	20	123	10	133
Ethanol	0.66	31	205	13	218
Methanol	0.49	41	271	16	287
LP Gas	0.70	28	115	125	240
CNG	0.20	102	109	600*	709
Batteries					
Sodium sulfur	0.03		27,200		
Lead acid	0.01		93,300		

* Aluminum tank(s)

Table 30. Methods of Storing Gaseous Hydrocarbon Fuels

Selected Characteristics

Technique	State	Natural Gas	LPG	Hydrogen
Compression	Gas	2400-3000 psi 4x gasoline vol Strong tank	Ambient conditions	Impractical: too large volume
Liquefaction	Liquid	-259°F. <60 psi	Ambient temp. 100 psi	-423°F. Best H_2 energy density
Adsorption	Solid	Clays, carbon <500 psi	Not required No advantage	Metal hydride: iron-titanium-heavy, magnesium-reltv light

General

Technique	Storage System	Comments
Compression	Pressurized tank	Bulky, added weight, limited fuel
Liquefaction	Insulated tank	Cryogenic for NG and H_2; boiloff
Adsorption	Insert porous materials	Heavy; limited fuel storage

Table 31. Transitional Vehicles (petroleum operation when new fuel not available)

Fuel	Dual-fuel Operator Choice	Bifuel Automatic Control
Gasoline Replacements:		
LP Gas	Available from after-market or by OEM special order. Deteriorated results on both fuels	
Natural Gas	Available from after-market. Deteriorated results on both fuels	
Alcohols		Experimental factory designs. Optimal results from FFV adaptation of gasoline engine
Diesel-Fuel Replacement:		
Natural Gas		Fumigated after-market systems available; worse emissions, up to 50% DF substitution
Alcohols	Early (1970's) experimental alcohol vaporizers not seriously considered for commercialization	

Table 32. Perceived Best Opportunities for Replacing Petroleum

Fuel/Energy Uses(s)	Propulsion	Technique	Use(s)	Propulsion	Technique
Alcohols	Light-duty SI	Flex-fuel FFV	Indvdl. fleet	Light-duty SI	Dedicated, optimized[a] Pvt. fleet
	Heavy-duty CI	Adapted diesel	Buses, fleet	Heavy-duty SI[c]	Dedicated, optimized[a] Fleet
NG	Light-duty SI	Dedicated	Fleet	Light-duty SI	Dedicated, advanced/optimized Fleet, pvt[b]
	Heavy-duty CI	Adapted diesel	Buses, fleet	Heavy-duty SI[c]	Dedicated, advanced/optimized Buses, fleet
LP Gas	Light-duty SI	Dedicated	Fleet	Light-duty SI	Dedicated, advanced/optimized Fleet, pvt[b]
	Medium-duty SI	Dedicated	Fleet	Heavy-duty SI[c]	Dedicated, advanced/optimized Buses, fleet
Electricity	Light-duty	Dedicated	Fleet	Light-duty	Dedicated, advanced battery Fleet, pvt[b]

[a] Same technique may apply to all designs, for example, direct injection, stratified charge, spark ignition ala DISC

[b] Dependent on range and performance compared to alternatives

[c] Ignition system dependent on future development

Table 33. Candidate First-Generation OEM Alternative-Fuel Vehicles

Fuel	Gasoline Substitute	Diesel Substitute
LP Gas	Dual-fuel and/or dedicated systems (production readiness)	
Ng	Dedicated systems (experimental design)	Dedicated heavy-duty systems (prototype design-limited special order)
Alcohols[a]	Flexible-variable fuel systems (preproduction)	Dedicated heavy-duty systems (experimental and prototype designs)
Electricity	Lead-acid or upgrade (early experimental)	

Note: Status included in parenthesis

[a] Light-duty systems presumably usable with either methanol or ethanol. Heavy-duty designs focus on methanol, but are adaptable to ethanol.

Table 34. Comparative Performance of Nominally Modified Stock Engines and Vehicles[a] (Midsize 4- to 5- Passenger Automobiles)

Characteristic	Methanol	LPG/Gasoline	LPG	NG/Gasoline	NG	Hydrogen
Power	- / 0	-	-- / 0	--	---	+
Acceleration	- / 0	-	--	--	---	+
Energy Economy	+ / 0	+ / 0	+ / 0	+ / 0	+ / 0	+
Emissions	+ / -	+ / -	+ / 0	+ / -	+ / -	+
Trunk Space	-	-	--	--	---	0
Vehicle Weight	0	0	-	-	--	0
Range:	0	0	--	0	---	-
Fueling Ease	-	-	--	--	---	-

Note: 0 is comparable to gasoline vehicle. - poorer. + better.

[a] Engine changes limited to fuel and ignition systems; fuel-system changes limited to materials change and necessary fuel preparation and engine-feed parts.

sions, range, and fueling convenience, as related to existing gasoline vehicles, would likely be as shown in Table 34 (OTA, 1990, Assessment of Costs and Benefits, 1988 and AMFUP, 1988 and 1982). For the most part, such pioneer or first-generation vehicles would be unlikely to entice motorists away from petroleum without additional incentives.

To provide low emissions, high efficiency (for example, good fuel economy), and desirable performance, the fuel-engine-vehicle system must be optimized. For example, Table 35 compares a number of factors affecting fuel economy of various gaseous hydrocarbons (EA-Mueller, 1988). A vehicle designed for a specific alternative fuel will provide advantages over a vehicle designed for gasoline or diesel fuel and retrofitted for use of the alternative fuel. The same characteristics shown in Table 35 for after-market conversions are shown for optimized designs in Table 36 (Assessment of Costs and Benefits, 1990) in the row labeled "Energy Economy." When optimized, all of the AFV technologies should do as well, or better, than conventional gasoline-powered vehicles. The quantitative ratings of the last two tables are translated into qualitative terms in Table 37.

All of the above leads one to the view that adequate technology exists to design and build vehicles that take good advantage of the inherent characteristics of the various alternative-fuel options. Differences in the characteristics (especially range and fuel availability) of the various fuels as applied to available engine technology reflect on operation such that LP Gas, natural gas, and battery-electricity use in highway vehicles will likely be initially selected primarily for niche applications, while alcohol-fuel vehicles are likely to beconsidered for a broader range of use.

6.3 Research, Development, and Demonstration Needs

In order that a fuel-engine-vehicle system can be expected to achieve commercial-market status, it is necessary that the three criteria of performance, availability, and economy, listed earlier, be met and that the entire resource-to-use chain be favorable. The research, development, and demonstration needed to achieve this goal for use of LP Gas, natural gas, and alcohol in spark- and compression-ignition engines and for use of battery EV's are summarized in Tables 38 to 44

Table 35. Potential Changes in Energy Economy for Equivalent Operation on Gaseous Fuels (engine optimized for fuel used)

Fuel	Change Due to Fuel Tank Weight	Engine-Efficiency Increase	Cold-Start Increase	Relative Energy Economy
CNG	-24%	+5%	+3.3%	84.3%
LNG	- 6%	+5%	+3.3%	102.3%
Propane	- 3%	+5%	+3.3%	105.3%
Butane	- 2%	0	+3.3%	101.3%
Biogas	-34%	0	+3.3%	69.3%

Source: "Gaseous fuels for Automotive Engines," Washington, D.C.: U.S. Department of Energy, 1980.

Table 36. Comparative Motor-Vehicle Performance on Various Fuels (hypothetical midsize 4-to-5 passenger automobile designed for optimal performance)

	Vehicle Type								
Characteristic	Diesel	DF[a] LPG/ Cnvntl	LPG	DF[a]NG/ Cnvntl	NG	Hydrogen	Electric	Meth/ Gsln (FFV)	Methanol (M–85)
Engine Size[b]	0	0	0	-	-	--	none	0	0
Power	0	0	0	--	0	0	0	+	++
Acceleration	-	-	-	-	0	-	+[c]	+	++
Trunk space	0	-	-	--	--	--	0	-	-
Vehicle Weight	0	0	0	--	-	---	---	0	-
Energy Economy	++	0	0	0	+	+		+	++
Range									
All Fuel		+	++	++	+			0/-	-
Subst Fuel	+	--	0	--	--	0	--	-	
Refueling	0	--	-	--	--	--	---	0	0

Note: 0 is comparable to gasoline vehicle, - poorer, + better

[a] Dual fuel

[b] Larger engine need is - (negative)

[c] At expense of range

Table 37. Relative Characteristics of Vehicles Operating on Alternative Fuels

Fuel-Energy	Power	Response	Efficiency	Range	Comment
Diesel	Nominal	Reduced	Good	High	Acceptable to most
Gasoline	Nominal	Nominal-good	Nominal	Good	Goal of new system
Ethanol	High		Improved	Nominal	Highly satisfactory
Methanol	High			Moderate	Highly satisfactory
LP Gas	Moderate		Nominal	Moderate	Acceptable
Natural Gas	Moderate			Marginal	Diesel performance
Electric	Nominal[a]	Good[a]	High	Marginal	Added power-response

Note: The ranking system from highest to lowest is high, good, improved, nominal, moderate, reduced, and marginal. Nominal is the midrange ranking.

[a] Use reduces range.

Table 38. Research, Development, and Demonstration Needs for Spark-Ignition Engines Using LP Gas

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	None	None	N/A	N/A
Development	None[a]	None	Fuel injection Electronic system	N/A	N/A
Demonstration	None	Self-service	OEN application of the above	N/A	N/A
Design	None	Domestic dispensing product	Technology comparable to gasoline	Spare parts	Technical courses
Economics	Growth impact	None	None	N/A	N/A
Environment	None	None	Measure OEM rslt	N/A	Verify results
Health/Safety	None	None	None	Precautions Safeguards	Education
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present business.

Table 39. Research, Development, and Demonstration Needs for Spark-Ignition Engines Using Natural Gas

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	Meter basics	Fuel storage	N/A	N/A
Development	None[a]	Accurate metering	Fuel injection Electronic system	N/A	N/A
Demonstration	None		OEN engines using advanced technology	N/A	N/A
Design	None	Low-cost meter	Technology compar-able to gasoline	Spare parts	Technical courses
Economics	Growth impact	None	None	N/A	N/A
Environment	None	None	Measure OEM results	N/A	Verify results
Health/Safety	None	National standards	Garaging standards	Precautions Safeguards	Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present business.

Table 40. Research, Development, and Demonstration Needs for Spark-Ignition Engines Using Alcohol Fuel

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	None	None	N/A	N/A
Development	None[a]	None	Optimized engine	N/A	N/A
Demonstration	None	None	Cold start and low aldehydes	N/A	N/A
Design	None	None	Production FFV's	Spare parts	Technical courses
Economics	Growth impact	None	None	N/A	N/A
Environment	None	None	Measure OEM results	N/A	Verify results
Health/Safety	None	National standards	Garaging standards	Precautions Safeguards	Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present uses.

Table 41. Research, Development, and Demonstration Needs for Compression-Ignition Engines Using LP Gas

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	None	None	N/A	N/A
Development	None[a]	None	Fuel injection Electronic system	N/A	N/A
Demonstration	None	Self-service	OEM application of the above	N/A	N/A
Design	None	Domestic dispensing product	Technology comparable to gasoline	Spare parts	Technical courses
Economics	Growth impact	None	None	N/A	N/A
Environment	None	None	Measure OEM results	N/A	Verify results
Health/Safety	None	None	None	Precautions	Education Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present business.

Table 42. Research, Development, and Demonstration Needs for Compression-Ignition Engines Using Natural Gas

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	Meter basics	Fuel storage	N/A	N/A
Development	None[a]	Accurate metering	Fuel injection Electronic system	N/A	N/A
Demonstration	None	Self-service	OEM application advanced technology	N/A	N/A
Design	None	Low cost meter Home compressor cost reduction	Technology comparable to diesel	Spare parts	Technical courses
Economics	Growth impact	None	None	N/A	N/A
Environment	None	None	Measure OEM results	N/A	Verify results
Health/Safety	None	National standards	Garaging standards	Precautions	Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present business.

Table 43. Research, Development, and Demonstration Needs for Compression-Ignition Engines Using Alcohol Fuel

Activity	Processing	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	None	None	N/A	N/A
Development	None[a]	None	Electronic system Optimized engine	N/A	N/A
Demonstration	None	None	OEM advanced tech-nology & engines	N/A	N/A
Design	None	None	Production models	Spare parts	Technical courses
Economics	Growth impact	None	Compare to clean diesels .	N/A	N/A
Environment	None	None	Measure OEM results Evaluate atmosph aldehyde effects	N/A	Verify results
Health/Safety	None	National standards	Garaging standards	Precautions	Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present uses.

Table 44. Research, Development, and Demonstration Needs for Electric Vehicles

Activity	Generation	Distribution	Vehicular	After-Market	Maintenance
Research	None[a]	None	Advanced batteries	None	N/A
Development	None[a]	None	System design incl accessories	N/A	N/A
Demonstration	None	None	OEM designs	N/A	N/A
Design	None	None	Production models	Spare parts	Technical courses
Economics	None	None	Manufacturing costs	N/A	N/A
Environment	None	None	Measure OEM results of non-elect equip aldehyde effects	N/A	N/A
Health/Safety	None	None	None	Precautions	Safeguards
Systems	None	None	None	N/A	N/A

[a] Industry R&D spurred by present uses.

(EAFUP, 1981). These tables provide a matrix of research, development, design, economics, environment, health and safety, and overall systems needs in each of the areas of fuel processing or electric generation, fuel-energy distribution, vehicle manufacture, vehicle after-market supply, and vehicle maintenance. In most instances, the needs for market introduction are presently satisfied or are straightforward in approach. Critical research needs exist primarily in the areas of fuel distribution and vehicle manufacture. Most of these are of a product-design nature that must be accomplished by individual industrial companies to suit their desires and approaches. From this, it is apparent that there are only a few key research needs and opportunities that are essential to successful market penetration. These are tied to inherent deficiencies in prime characteristics that weaken the competitive position in relation to other options.

A significant potential problem and need is that technology and the market are dynamic, and that regulations require improvements in technology and design with time. Thus, AFV's must aim at replacement of improved conventional systems that will, or otherwise would, exist in the first two decades of the 21st century.

The eventual optimized vehicle systems using alternative fuels will be appreciably different than those used today. Before the "final" system becomes a widespread reality, interim, or transitional systems will exist. Many of these will be limited to fleets with dedicated refueling facilities or specialized needs. A popular candidate for more widespread use is the flexible- or variable-fuel concept in which good engine performance can be obtained from more than one fuel. At this time, and for the foreseeable future, this is limited to liquid-fuel application. If the market grows to such an extent that fuel becomes readily available, the next step may be to favor performance on alcohol fuel, with a limp-home capability on gasoline (alcohol-enhanced, gasoline-emergency vehicle) (OTA, 1990). Gaseous hydrocarbon fuels will likely be of the dual-fuel variety unless or until a simple fuel-injection system is achieved. Such achievement might permit development of a flexible-variable fuel design for gaseous fuels offering appreciably better results. EV applications are almost totally dependent on success in advanced-battery development. Battery-vehicle systems that overcome cold temperature obstacles would offer the opportunity for use in much broader geographical areas (OTA, 1990).

6.4 Key Research Needs

Industry, partially supported by government and trade association funds, is addressing applications development on a broad basis, ranging from fuel storage to dispensing to vehicle-system design (Windsor Workshops and SAE). As we have noted, many of the actions required to provide viable commercial products, or demonstrations thereof, consist of product development. A review of industry activity shows that the ongoing effort addresses this very well. In addition, ongoing investigation addresses technology that will provide improvements in products and manufacturing economics. Removal of these research, development, and demonstration needs from the charts of Tables 38 to 44 leave a few key items requiring research related to initial market penetration.

In late 1990, The Society of Automotive Engineers sponsored a topical technical (Toptech) workshop as part of its Continuing Professional Development Program, which addressed optimized methanol and natural gas vehicles and associated R&D needs. The resulting R&D needs, as printed in the proceedings, are listed in Table 45 (SAE, 1991). Using the same differentiation they used between product-oriented and fundamental needs as for the previous charts, we obtain the research needs summarized in Table 46 and discussed below in more detail.

6.4.1 Basic Engine and Combustion Phenomena

Many of the needs relate to greater understanding of basic engine and combustion phenomena. Much, if not most, of this is applicable to all fuels. Associated with these are the constant needs for improved instrumentation to aid in the work. The advent of alternative fuels only heightens the needs.

Table 45. SAE Workshop Consensus Description of Research and Development Needs for Methanol and Natural Gas Vehicles

Methanol
• Research on in-cylinder phenomena involved in formation and control of pollutants.
• Sensors and control systems for precise control of engine parameters. Detection of onset of abnormal combustion is desired.
• Catalyst systems—refinements and reformulations necessary for improved reductions in emissions, including formaldehyde. Catalysts integral with engine design, close-coupled, heated, and so forth.
• Research to quantify the relative air quality implications between M–85 and M–100. Relative implications of various primers for M–85. Research should address both normal and cold-weather implications.
• Development of cold-start systems for M–100.
• Research into ways to determine in-cylinder A/F distribution or air-vapor distribution during cold engine situation.
• Improved models of fuel-air behavior in manifolds and cylinders.
• Understanding why differences exist between using same fuel and same cold-start system.
Natural Gas
• Better and different types of sensors for individual cylinder feedback control.
• Catalysts for lean-burn engines, to handle NO_x reduction.
• Fuel standard to eliminate variability in contaminants present from site to site.
• Fuel-tank recertification, required frequency, and procedures.
• Boiloff handling from LNG tanks to reduce evaporative emissions.
• Novel gas storage schemes to increase vehicle range, safety, or both.
• Electronic fuel-injection systems with proven durability.
• Better understanding of flame initiation and propagation and how these are influenced by induction system, combustion chamber, and ignition system parameters.

Source: "*Optimized Methanol and Natural Gas Fueled Vehicles Toptech*," September 12-13, 1990, Knoxville, TN. Continuing Professional Development Program, Warrendale, PA, Society of Automotive Engineers, 1991.

Table 46. Key Technical Deficiencies and Needs for Broad Use of Alternative-Fuel Vehicles

Fuel/Energy	Deficiency	Need	Prospect
Syn fuel	Hydrocarbon output	Lower HC and NO_x	Equates to petroleum role
LPG (propane)	Carburetion limitations	Fuel injection/ electronic control	Hard to achieve liquid-fuel results
Natural gas (methane)	Low-energy density	Greatly improved storage technology FI/electr control	Need breakthrough in fundamental knowledge Hard to achieve liquid rslt
Hydrogen	Low-energy density Low engine power	Storage technology Larger engine	Need fundamental breakthrough. Moderate performance
Alcohols	Med energy density Higher aldehydes Gasoline additives	Design ingenuity Appropriate design Better additives	Reasonable offset Acceptable results Very difficult
Electric vehicle	Low-energy density Cold-temp overload	Advanced battery Add energy source	Moderate; best possible will only serve niches Limited to mild climate use
General:			
Combustion	Understanding basic phenomenon	Greater insight	Constant need and effort
Catalysts	NO_x at lean burn	Lean-burn NO_x catalyst	Unknown
Reciprocating engine	Understanding basic phenomenon	Greater insight	Constant need and effort
Continuous cmbstn eng	Limitations of recip IC engines	Better operation	Unknown
Exhaust sensors	Stoichmtry sensing No species ident	Lean-burn control Specie sensitive	Probably reasonable Probably reasonable
Aldehyde fate	Unexplored	Invstgt exhaust vs atmos source	Good for source effects Impacts unknown
Hydrogen fuel	Very little R&D	Insurance against global warm need	Need is judgmental
Instrumentation	Needs increase with progress	Improved tech-niques	Constant need and effort
Prof education	Few experts	Establish policy	Good, inexpensive

6.4.2 Gaseous-Fuel Storage

The major problem in gaseous-fuel storage is that the energy density of such fuels is very low, providing an inherently difficult obstacle. Present techniques, even if optimized, may provide marginally acceptable driving range, but will not offer sufficient benefits for general marketability (Stephenson, 1990, Aerospace, 1985 and AFUP, 1985). Thus, a technological breakthrough in storage technology is required. Research is needed if this is to be overcome, addressing the understanding of fundamentals in storage science, such as surface adsorption of hydrocarbons and the makeup and manipulation of hydrogen interstices.

6.4.3 Gaseous-Fuel Injection

Significant improvement in technology and simplification of equipment is required for gaseous-fuel metering and manipulation to equate to that used in conventional liquid-fuel engine systems. Here, too, is a difficult obstacle to developing comparably optimized gaseous-fuel engine systems. One system under development is approaching commercial introduction, but it is relatively complex and probably limited by economics to larger engine sizes (for example, medium- to heavy-duty trucks) (Carter, 1991). Unique approaches that can revolutionize gaseous-fuel-injection results are required. Entrepreneurial companies are offering potential solutions, and the Department of Energy is evaluating these options.

6.4.4 Gaseous-Propulsion Equipment

In view of the limitations of gaseous-fuel application to intermittent internal combustion engines, a reconsideration may be in order of the ramifications of gaseous-fuel use in other engine types, particularly continuous combustion engines (for example, Brayton and Sterling cycles). This needs to be approached with specific goals in mi , because it will be necessary for resulting technology to offer significant advantages over existing propulsion systems to attract commercial interest.

6.4.5 Fuel Additive(s) for Alcohols

Several deficiencies of alcohols (notably poor cold-starting and driveaway, invisible flame, and pleasant taste) are presently overcome by adding gasoline. This mitigates the environmental and energy security benefits. Investigation of chemicals to replace or minimize the amount of gasoline needed to date have not offered much help (Russell, 1991). Technology to achieve maximum alcohol concentration while minimizing problems is highly desirable.

6.4.6 Emissions and Environment

Vehicle-related environmental activity typically centers on vehicle emissions. Atmospheric reactions and results are much harder to evaluate and assess, and the results are only illustrative because of the chemical complexities, atmospheric dynamics, and computational difficulties. One aspect that has been neglected to date is that of evaluating aldehyde effects from alcohol vehicles on the atmosphere. Past studies of aldehydes relate primarily to their development from other hydrocarbons as a consequence of atmospheric chemical reactions and the consequences thereof. Compared to many other atmospheric gases, the aldehydes are not long lived nor transported for great distances. Aldehyde emissions from alcohol engines are appreciably greater than those from petroleum engines, though low in actual value. Most of these are engine generated and are already reacting with other hydrocarbons as they traverse the exhaust system (ORNL Report, 1987, and Texaco, 1985). The fate of these may well be quite different than for the aldehydes created in the atmosphere. Limited work in this area suggested that the effect of aldehydes from the fuel may be appreciably less than similar amounts generated in the atmosphere.

Control of engine emissions is a continuing problem for conventional vehicles, despite enormous progress. Alternative fuels provide an opportunity for progress not available from petroleum products in that they support combustion of leaner fuel to air mixtures. This feature is or can be associated with lower emissions of carbon monoxide and nitrogen oxides, without necessarily resulting in increased hydrocarbon output

(Brown, 1991). Further, alcohols (especially methanol) burn cooler, and thereby yield reduced oxides of nitrogen. Present electronic (feedback) emission control systems use a sensor to control the fuel to air ratio to stoichiometry (just enough air to theoretically burn all of the fuel) and three-way catalysts to reduce the amount of the three earlier noted emissions species. Sensors to effectively control the mixture for leaner combustion or to monitor the level of the exhaust species or to do both, could help achieve maximum emissions benefits from alternative fuels.

Use of natural gas in lean-burn systems results in very low emissions with the possible exception of oxides of nitrogen. Existing catalysts that reduce nitrogen oxides do not operate in this oxygen-rich regime. Thus, development of such a catalyst device would offer greatly improved results. Recent developments indicate that this is an enormously promising area for research (SAE Toptech, 1991).

6.4.7 Global Warming Implications

Increasing concern regarding global warming suggests that although hydrogen use as a vehicular fuel is of long-range interest, there may be reason for some modest level of R&D to be conducted as preparatory insurance. The National Academy of Sciences has recommended substantial reduction in use of fossil (that is, carbon containing) fuels (IGT Highlights, 1991). To the degree that hydrogen can be used, as in niche applications, the situation will be aided.

6.4.8 Professional Education

The impressive development of fundamental information on and application of use of alternative transportation fuels has been conducted by a surprisingly small group of scientific investigators. These number well under 100, and were associated with about a dozen key institutions (business and educational) and a like number with lesser involvement. Even with some recent commitment to initial commercial design, the number of participants is not impressive, and most are specialists in areas other than fuels. In addition, a great many of those who contributed to the currently available information have retired. The system has not provided enough new participants to fully replace these. If alternative fuels are to achieve commercial success and flourish, the number of experts needs to mushroom (Ecklund, 1989). Educational support is a necessity, but there are hardly enough R&D funds expended in this area to provide for more than a *few* graduate students at a time. Support of graduate students is not expensive, and provides a source of expanded technology vital to a healthy endeavor.

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