SOUTHERN CALIFORNIA
RAPID TRANSIT DISTRICT

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JACK R. GILSTRAP
GENERAL MANAGER

TO: Mr. George W. Heinle DATE: January 23, 1973

FROM: George H. Powell

SUBJECT: LETTER OF TRANSMITTAL

Attached is a copy of the staff's report on "Alternative Fuels for Automobiles and Trucks." This report is intended to be advisory in nature and is not to be construed as a criticism of any of the agencies that were contacted.

This study is for the sole use of Southern California Rapid Transit District in determining the feasibility of gaseous fuels in automobiles, light trucks and Minibuses.

I concur with the conclusions and recommendations of the staff.

GEORGE H. POWELL
General Superintendent
of Maintenance and Equipment

GHP:ki

Attachment

ALTERNATE FUELS FOR AUTOMOBILES AND TRUCKS

January 23, 1973

Southern California Rapid Transit District

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ACKNOWLEDGEMENTS

Southern California Rapid Transit District is pleased to acknowledge the assistance of personnel from the San Diego Gas and Electric Company, Mr. Paul Hathaway, and the Petrolane Incorporated, Mr. Tom Laubach. We also acknowledge the assistance of the many organizations listed in Appendix A, who provided current information on many important aspects of this report.

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ALTERNATE FUELS FOR AUTOMOBILES AND TRUCKS

I. PURPOSE

The Southern California Rapid Transit District, along with other agencies, is concerned with improving the air quality in our environment. Accordingly, the District's staff has made a study of what other agencies and corporations are doing relative to the use of alternate fuels for gasoline.

The purpose of this project is to determine the practicability of using gaseous fuels in the District's automobiles, light trucks and Minibuses. The specific purpose is to answer the following questions:

1. Do alternate fuels have sufficient mileage capabilities?
2. Are alternate fuels economically practical?
3. What are the emission advantages, if any, as compared to gasoline?
4. Are alternate fuels safe?

II. BACKGROUND

Only certain gaseous fuels were studied: compressed natural gas (CNG), liquefied natural gas (LNG), and liquefied petroleum gas (LPG or propane). Several governmental agencies, fleet operators, and fuel distributors were contacted by telephone. The District's predecessors' experience was researched. Reference is made to studies by others, such as "The Benefits and Risks Associated With Gaseous Fuel Vehicles" by Arthur D. Little, Inc.[1].

III. EXPERIENCE OF AGENCIES AND FLEET OPERATORS

A. Compressed Natural Gas (CNG)

1. L.A. County Mechanical Department:

L.A. County has discontinued their tests of CNG in automobiles and light trucks. They concluded that CNG was not practical as a vehicle fuel as it lacked the capacity to provide sufficient mileage range.

2. Riverside County:

Riverside County phased out the use of CNG as a vehicle fuel in 1970 as this fuel was not readily available at outlying locations and it lacked sufficient range for their needs. Riverside had many complaints by drivers of too much loss of power.

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1. Report to the Massachusetts Turnpike Authority, May 5, 1972.

3. City of Los Angeles Transportation Department:

The City is no longer using CNG as a vehicle fuel. The test results indicated a loss of power and limited mileage range.

4. State of California, Division of Highways:

The State has concluded that CNG as a vehicle fuel, lacks sufficient mileage range and gives poor acceleration and performance resulting in driver unacceptability. The cost of maintenance is higher on CNG than on LNG or gasoline. Drivers' complaints are numerous and must be checked out.

The Division of Highways had fires on two units while they were operating on CNG. High pressure developed in the gasoline line from the fuel pump to the carburetor, rupturing the rubber hose, spilling gasoline over the engine, which was ignited. Investigation revealed that there was no by-pass or relief in the fuel pump.

The State is presently phasing out the use of all CNG by attrition. As a vehicle wears out or is wrecked, it is replaced with one that uses gasoline.

5. United States General Services Administration (GSA):

GSA has operated 85 vehicles on dual fuel systems, gasoline, and CNG, for approximately two years.

They state that they have had no real problems except that the drivers do not want to come in for refueling of natural gas.

The GSA does not expect to expand the program at this time.

6. District's Experience:

The District operated one large 50-passenger bus on CNG from April 1971 to March 1972. This bus had to be fueled twice a day to provide an operating range of 105 miles. The District has also operated 19 Minibuses on dual fuel systems of compressed natural gas and gasoline. These buses have accumulated approximately 388,000 miles and have averaged 3.3 miles per unit of fuel. The driving range is not sufficient to allow these buses to operate on natural gas alone. 39% of the Minibus miles are operated on gasoline.

There were three explosions in the engines of the Minibuses during November 1972. These explosions might have been prevented with the use of flame arresters in the positive crankcase ventilating by-pass line to the carburetor air intake. These arresters were inadvertently omitted by the factory.

B. Liquefied Natural Gas (LNG)

1. United States General Services Administration:

GSA is operating 140 sedans on dual fuel systems, gasoline and LNG. These vehicles are assigned to the LAX motor pool at 96th and Airport Avenue, near the Los Angeles Airport.

Drivers picking up automobiles are instructed in the use of the dual fuel systems and are encouraged to use the LNG. Once out of the area, the driver does what he wants to.

Mr. Herbert Olson, Assistant Director Motor Equipment, and Project Manager, claims it takes 3 to 4 minutes to fill 18 to 20 gallon tanks.

No figures are available in the Los Angeles area relative to cost, miles per gallon, etc. Mr. Olson indicated that the fuel mileage is the same for LNG as for gasoline. On January 15, 1973, a flash fire occurred in a LNG vehicle as a result of a procedural error. This was the first fire in millions of miles during the last three years. (For more details, see Section H. Safety, 2. LNG, on page 12.)

2. State of California, Division of Highways:

Beginning in 1970, the Division of Highways instituted a test on LNG in 25 vehicles; 10 pickups and 15 sedans. During 1972, it was necessary to discontinue the LNG in the ten trucks as they lacked fuel capacity to make them flexible. The State does not anticipate any expansion of the LNG program, at this time.

C. Liquefied Petroleum Gas (LPG or Propane)

1. City of Los Angeles, Transportation Department:

The City discontinued the use of LPG in one of the Councilmen's automobiles during 1972. They are presently operating no gaseous fuel vehicles and have been specifying diesel, when replacing heavy-duty equipment, and gasoline for all new automobiles.

2. State of California, Division of Highways:

The Division of Highways is presently operating 53 vehicles on LPG in the South Coast Basin. Ten more LPG fuel vehicles will be added within the next 30 days. These vehicles are operating in Los Angeles, Orange and Riverside Counties. Vehicles using propane have been more successful than those operating on natural gas. The LPG has the required operating range, is more acceptable to employees, and has a lower loss of power than that of natural gas. LPG is available throughout the Southern California area.

3. Los Angeles County, Mechanical Department:

The County has no vehicles operating on LPG but does have several infrequently used stationary engines operating on this fuel, such as, those operating air raid sirens. These engines were converted to propane as the gasoline had a tendency of going stale, creating hard start problems.

4. Riverside County:

Since 1970, the County of Riverside has equipped 80 vehicles; 24 trucks and 56 automobiles, to operate on LPG. These units are a mixture of Chevrolets, Plymouths, Fords, etc. Nothing was done with the engine parts such as valves or valve seats when making the conversion. Riverside has experienced a great deal of problems relating to burnt valves and valve seats. They have experienced about a 33% loss of power.

During the week of December 11, 1972, a Dodge van failed to accept fuel from a propane station in Blythe, California. The windows of the van were open. The two employees drove some distance from the fuel station when one attempted to light a cigarette and the van blew up. The van was a total loss. The two employees are still in the hospital, badly burned.

The Board of Supervisors grounded the use of propane vehicles but has since changed their decision and are continuing the use of propane with the provision that there is to be no smoking in, on, or about these propane fueled units.

5. Von's Market, El Monte, California:

Von's Market has been operating 85 trucks on propane since 1956. They have had many problems with cylinder heads, head gaskets and valve guides. These vehicles are averaging about 3.0 miles per gallon on propane and are pulling a gross vehicle weight of 76,800 pounds.

One of the advantages that Von's has in the use of propane is that this fuel is used as a standby for their bake ovens.

Their newest equipment, 15 trucks, are equipped with GMC 8V-71 diesel engines. All of their automobiles are leased and operate on gasoline. Von's reports no serious problems of fire.

6. Certified Grocers, City of Commerce:

Certified Grocers operates about 200 trucks. In 1971, 100 units were operating on propane, and the other 100 units on diesel. During 1972, they phased out 40 to 50 propane units and have replaced them with diesels. Certified has 40 new diesel trucks on order to be delivered in the early part of 1973 to replace 40 of the propane units. All new trucks to be purchased will be equipped with diesel engines.

Cylinder heads and exhaust valves have been a major problem. Maintenance of the diesel engine is more economical than that of propane.

7. District's Experience:

The District and its predecessors had no experience with the use of LPG in automobiles, but they have had extensive experience with its use in buses.

Twenty White buses were operated on LPG by the Los Angeles Railway Company from 1928 until 1942. Four Twin Coach buses were operated on LPG from 1935 until 1942. All 24 buses were converted in 1942 to utilize gasoline. During the time that these buses operated on LPG, one fire occurred at the Division 2 yards when fuel leaked from a dispenser and crept into an area containing a hot tank. The LPG ignited. No record of the amount of damage is available at this time.

Another of RTD's predecessors was involved with the use of LPG. The Asbury Rapid Transit System and its successors operated 36 propane fuel buses from 1951 until 1959. These units were removed from service and eventually sold.

Two incidents were reported relative to the safety feature of using propane. In one incident, a bus caught fire in a lay-over zone in Hollywood, severely damaging the bus but with no injuries to the passengers or to the driver. In a second incident, a serviceman drove a bus away from the fuel island at the Glendale Division without disconnecting the dispenser line. The hose broke and the safety check valve failed to function properly, allowing approximately 2,500 gallons of propane to pour out into the yard. Alert action by the employees in shutting down all gas fired pilots and prohibiting buses from entering the yard avoided ignition and there was no fire.

IV. COMPARATIVE ANALYSIS

A. Emissions

1. In comparison to gasoline, both propane and natural gas offer a substantial advantage from the emissions standpoint. The use of a lean mixture with these alternate fuels, while reducing performance, results in an exhaust which is low in hydrocarbons and carbon monoxide. The oxides of nitrogen may be lowered by removing the ignition advance mechanism in the distributor or by re-circulating some of the exhaust gas.

   The Arthur D. Little, Inc. Study concludes that:

   > Emissions from these gaseous fuels approach the standard set for 1975 automobiles, but are not lower than those proposed for 1975 automobiles operating on gasoline as a fuel. Therefore, in terms of reducing automobile pollution, it appears that the main impact would be obtained from the conversion of 1970-1974 model vehicles to gaseous fuels. 1975 and later models could not be converted but vehicles on the road would continue to be used. Further developments may improve emission levels of gaseous fuels to the point where these vehicles can meet the 1975-1976 standards, but this may require emission control equipment similar to that proposed for gasoline vehicles. Therefore, it appears that any impetus for conversion after 1975 must rely heavily on technical, economical advantages over gasoline.[1]

2. Extensive work is being done by the major automobile manufacturers in lowering the emission level of gasoline vehicles. The Division of Highways, State of California, is testing several 1973 GMC automobiles equipped with GMC's 1975 low emissions package, including a catalytic convertor. The emissions from these automobiles meet the 1975 standards.[2] As these vehicles have accumulated limited mileage (about 6,000 miles each), it is impossible to predict the future emissions. One 1973 Oldsmobile is averaging better than 12 miles per gallon.

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1. Shooter, Douglas and Kalelkar, Ashok, The Benefits and Risks Associated With Gaseous Fueled Vehicles, May 5, 1972, p. 19.

2. 1975/76 Federal Emissions Standards (Grams/Vehicle Mile)
   Hydrocarbons - 0.41 Carbon Monoxide - 3.4 Nitrogen Oxides - 0.4*
   *Nitrogen oxides standard does not apply until 1976.

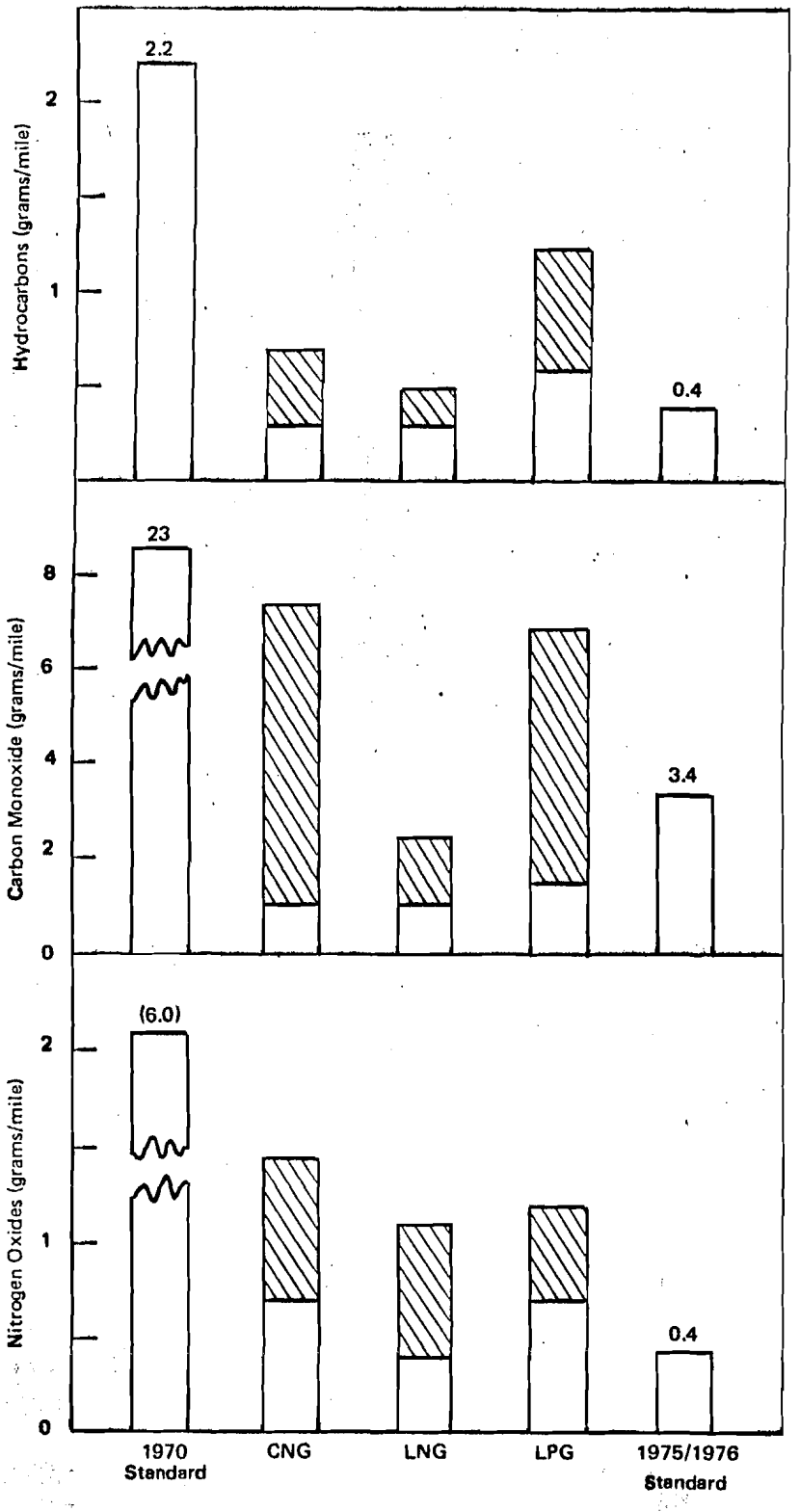

FIGURE 4 EXHAUST EMISSIONS FROM GASEOUS FUELS COMPARED TO THE 1970 AND 1975/76 FEDERAL STANDARDS

B. Cost of Conversion

1. C.N.G.

The cost of converting a sedan to operate on CNG is about $600. This figure can change, depending on the number and size of tanks and the configuration of the vehicle's trunk and the miles that the vehicle is required to travel on one filling of fuel.

2. L.N.G.

The cost of converting from gasoline to LNG varies greatly with those agencies contacted. The Federal government converted to a dual fuel system, LNG and gasoline. The LNG required an 18 gallon tank. This kept their cost down to approximately $650 each. The State converted to strictly LNG and, therefore, required two 18 gallon tanks in order to fit the configuration and the size of the trunk compartments and allow the sedans a reasonable operating range. The State paid up to $1,200 per vehicle for conversion.

As LNG is not available except in certain areas, the volume of the tank would have to be great enough to provide sufficient fuel for the anticipated mileage. These tanks use up some of the trunk space. It is estimated that LNG conversions in automobiles would cost between $900 and $1,200.

3. L.P.G.

The conversion cost of providing LPG systems ranged from $250-$500. Many tank configurations and various types of equipment are available. The Petrolane Corporation in Los Angeles estimates the average conversion cost for an automobile is between $450-$500.

C. Cost of Fueling Facility

1. C.N.G.

The State of California, Division of Highways, had a CNG fueling facility installed at Second and Spring Streets in Los Angeles, at a cost between $45,000-$50,000.

The capital cost of providing a CNG fueling facility can vary from $12,000-$50,000,[1] depending upon the number of vehicles, the capacity of the tanks and the fueling rate required. A simple slow fill system utilizing two, 35 CFM compressors, driven by two, 25 H.P. electric motors, with 20 fill positions,

1. Estimate - September 22, 1971 - R.E. Huff to Samuel Black Memo

may be installed for approximately $12,000. The same compressors and motors would be used for a quick fill system but would require storage facilities, bringing the cost up to as high as $53,000. Slow fill fueling systems may be leased for approximately $850 per month. The quick fill systems may be leased for approximately $1,100-$1,200 per month.

2. L.N.G.

Mr. Paul Hathaway of San Diego Gas and Electric Company estimated that a 10,000 gallon fueling facility, completely installed as a closed system, including necessary pumps, piping and four dispensers, will cost in the neighborhood of $175,000.

3. L.P.G.

On December 14, 1972, Mr. Tom Laubach of Petrolane, Inc., estimated that an 18,000 gallon tank and fueling dispensers could be installed at Division 3 for approximately $19,615. This tank has a usable volume of 14,400 gallons. This tank may be leased from Petrolane, Inc. for $150 per month. Delivery and installation costs of approximately $4,500 to $5,000 would have to be borne by the District.

Three, 1,150 gallon tanks, with a usable capacity of 2,600 gallons could be leased for approximately $300 a year.

D. Cost of Fuel

1. C.N.G.

The State of California, Division of Highways, pay 7¢ per 100 cubic feet of fuel. One hundred cubic feet of CNG is considered equal to one gallon of gasoline. Their studies indicate that it costs between 3¢-5¢ per 100 cubic feet to compress. The total cost of fuel is estimated to be 10¢-12¢ per 100 cubic feet.

The District has been paying 23¢ per 100 cubic feet of CNG delivered to our Minibuses.

2. L.N.G.

The State of California, Division of Highways in San Diego, California, pays the San Diego Gas and Electric Company 16¢ per gallon of LNG. This price includes the lease of a storage facility that contains between 2,500-3,000 gallons of LNG.

Gasoline

Mr. Paul Hathaway of San Diego Gas and Electric Company estimated that they could deliver fuel to Los Angeles for 18¢-20¢ per gallon, providing the District had a storage tank with the capacity of 10,000 gallons. The bulk cost at their dock is 15¢ per gallon.

3. L.P.G.

The State of California, Division of Highways, is paying 11¢ per gallon (no tax) for LPG delivered to Orange County in 10,000 gallon lots.

Mr. Laubach of Petrolane, Inc., estimates that the cost of fuel would be 9¢ per gallon, delivered in 10,000 gallon lots to the District's Division 3 yard. In lots of 2,000 gallons, LPG would cost in the neighborhood of 12¢-14¢ per gallon.

E. Maintenance Cost

1. C.N.G.

While exact figures are not available, the State of California, Division of Highways, indicated that the cost of maintaining CNG equipped vehicles is greater than that of gasoline due to the many complaints of poor performance. The District's experience is similar in that carburetion and solenoid related problems have been very great.

2. L.N.G.

The agencies contacted indicated that the maintenance of LNG fueled equipment is approximately the same as for gasoline. The United States General Services Administration indicated that the cents per mile maintenance cost was slightly lower on LNG than on gasoline. No figures are available in the Los Angeles area for confirmation.

3. L.P.G.

Most agencies contacted indicated that the maintenance cost of LPG fueled automobiles was no greater than that for gasoline fueled vehicles. Riverside County stated that their problems with valves, including tow charges, have increased the cost of maintenance above the cost to maintain gasoline fueled vehicles. Those agencies operating heavy duty vehicles indicated that the cost of maintenance of LPG fueled equipment is greater than that for diesel fueled equipment.

F. Mileage Range

1. C.N.G.

All agencies contacted indicated that the mileage range of CNG was insufficient and could be only used in conjunction with another fuel. The District's experience confirmed the results of others.

2. L.N.G.

The General Services Administration of the United States government, indicated that the mileage range of LNG was not great enough to afford a single fuel system. There are insufficient fueling stations to allow the utilization of this fuel in outlying areas.

The Division of Highways of the State of California, indicated that their sedans equipped to operate on LNG had sufficient capacity for their required mileage in the local area of San Diego.

3. L.P.G.

Those agencies contacted indicated that LPG fueled automobiles and light trucks had the capacity to fulfill a regular day's operation. They also indicated that LPG was available in most outlying areas.

G. Performance

1. C.N.G.

Most agencies stated that their CNG operated vehicles gave poor performance which resulted in complaints of poor acceleration, hard steering, loss of stability at high speeds and poor brakes.

2. L.N.G.

Those agencies contacted stated that there was little loss of power when using LNG. The General Services Administration of the United States government, utilizes a dual fuel system. Once leaving LAX, most miles are operated on gasoline. The Division of Highways of the State of California, utilizing a single fuel system, is able to tune their engines to obtain maximum performance on LNG.

3. L.P.G.

Most agencies contacted stated that there was little loss of power when using LPG. Riverside County indicated approximately 33% loss of power. Any loss of power in a single fueled vehicle may be offset by obtaining a slightly larger engine. This would be equivalent to de-rating the horsepower of the engine in order to improve emissions.

H. Safety

1. C.N.G.

Explosions from rupture of CNG tanks is very unlikely as these tanks are constructed to contain a pressure far in excess of the normal operating pressures. These tanks are also equipped with safety discs to relieve the pressure at a pre-determined amount.

The Arthur D. Little, Inc. study concluded:

> That failure of the fuel tank could only occur from external heat due to a fire and only then if the relief devices are inadequate or fail to operate properly. If the fuel tank would rupture in the presence of a fire, it would produce a blast wave from the rapid expansion of the fuel, resulting in a deflagration, but not detonation.[1]

The District's experience of two explosions in engines was the result of the factory leaving flame arresters out of the positive crankcase ventilation line to the carburetor intake. This can only be considered as a man failure and should not be construed as failure of the gas system. Likewise, the two fires that occurred on the CNG-Gasoline vehicles operated by the State were the responsibility of people. The build up of pressure in the gasoline line, from the pump to the carburetor, would not have occurred if the proper equipment had been used. Therefore, it is necessary that equipment and systems be properly designed and installed to insure adequate safety.

2. L.N.G.

The General Services Administration of the United States government reported one flash fire after millions of miles of operation. Preliminary investigation revealed that the driver had opened a manual tank vent to lower the pressure

1. Arthur D. Little, Inc. Study, The Benefits and Risks Associated With Gaseous Fueled Vehicles, May 5, 1972, p. 75

to overcome a "choked" condition. A procedure not recommended. Vapor filled the trunk compartment and seeped into the passenger area. When the driver turned on the ignition, a flash fire occurred, blowing out the windows. The driver was treated in the hospital for shock and released the following day.

LNG tanks generally have an operating pressure 20-30 PSI and are of sufficient thickness to prevent any real hazard of explosion except from external fires.

It would appear that well designed, properly installed and maintained systems are as safe as gasoline systems.

3. L.P.G.

The Arthur D. Little, Inc. Study states:

> Records of LPG accidents show that explosion can occur from external heating under extreme conditions if the relief devices fail or are inadequate. It is an infrequent occurrence if the system is properly designed and constructed.[1]

The probability of an explosion of the tank is almost nil. The real danger exists from the fact that LPG is heavier than air and, in the event of a leak, this fuel puddles and may creep along the ground until it is dissipated or is ignited by an external flame.

The Chicago Transit Authority had a fire in which two buses were destroyed. A propane bus, while being fueled at the service station, was struck from behind by a diesel bus, rupturing a fuel line. The fuel spread across the pavement entering the diesel bus and apparently was ignited by the spark of a heater motor which was in operation. These freak accidents can and do happen.

4. Gasoline

The Arthur D. Little, Inc. Study concludes that:

> Gasoline tanks are more likely to explode on impact than gaseous fuel tanks. Therefore, the risk to occupants is significantlylower for gaseous fuel systems. However, the potential for damage from explosion to closed structures, such as tunnels, is higher for gaseous systems since the tanks can build up larger amounts of potential energy prior to rupture.[2]

1. Arthur D. Little Inc. Study, The Benefits and Risks Associated With Gaseous Fueled Vehicles, May 5, 1972, p. 75.
2. Ibid, p. 80.

I. COMPARATIVE ANALYSIS

AGENCY	FUELS	PROBLEMS	RESULTS	ACTION	COST/CONVERSION	COST/FUEL	COST/STATION	MPG/100 Cu.Ft.	RANGE
U.S. Govt. G.S.A.	Dual Fuel(CNG Gasoline)	Difficult to get driver's to get CNG	Status quo	Continuing use	$250-$300	-	-	-	Insufficient as independent fuel
U.S. Govt. G.S.A.	Dual Fuel(LNG Gasoline)	Difficult to get driver's to get LNG	Status quo	Continuing use	$650	NA	Fuel dispensed by San Diego Gas and Electric	*NA	Insufficient as independent fuel
State of California, Div. of Highways	Dual Fuel(CNG Gasoline)	Poor performance	Status quo	Discontinuing use by attrition	$250-$300	.07-100 cu.ft. .03-.05 to compress .10-.12-100 cu.ft.	$45-$50,000	8-9	Insufficient as independent fuel
State of California, Div. of Highways	LNG(Trucks)	Insufficient mileage	Not flexible	Discontinued use	$800	.16	Facility furnished by San Diego Gas and Electric price	*NA	Insufficient as independent fuel
State of California, Div. of Highways	LNG(Autos)	Limited to San Diego area	Status quo	Continuing use	$1,200	.16	Incl. in fuel	12-13	36 gals.- 400 miles
State of California, Div. of Highways	LPG	-	-	Expanding program	$450	.11 No tax	$9,000 + labor	12-13	30 gals.- 350+
City of L.A. Transp. Dept.	Dual Fuel(CNG Gasoline)	Insufficient mileage, poor performance	Recommended discontinuance	Discontinued	-	-	-	-	Insufficient as independent fuel
City of L.A. Transp. Dept.	LPG	-	Only 1 unit tested	Discontinued	-	Purchased fuel at public stations		-	-
L.A. County Mech. Dept.	Dual Fuel(CNG Gasoline)	Insufficient mileage, poor performance	Recommended discontinuance	Discontinued	-	-	-	-	Insufficient as independent fuel
Riverside County	Dual Fuel(CNG Gasoline)	Insufficient mileage, poor performance	Recommended discontinuance	Discontinued	-	-	-	-	Insufficient as independent fuel
Riverside County	LPG	30% loss of power, considerable burning of valves, seats and pistons	Supt. recommended discontinuance to board	Continuing use	$260 small units .14 $460 lge.sedans		$4,000 for hardware Tank incl. price of fuel	10-12	Compacts 180 miles Large sedans 280 miles
Von's Mkt.	LPG	Cyl. head gaskets and valves	Status quo	Continuing use	-	-	-	3.0	-
Certified Grocers	LPG	Cyl. head and valves	Recommended replace with diesel	Phasing out Replacing with diesel					
Latest Estimate to Dist.	LNG	-	-	-	$900	.18-.20	$100,000-$175,000 (Depending on use of used equipment)		
"	LPG	-	-	-	$450-$500-sedans	.09-.14	$ 19,165		

*NA - Not available

V. CONCLUSIONS

Most agencies consider the three alternate fuels safe when the systems are properly designed, installed and maintained. The use of these alternate fuels do not necessarily result in low exhaust emissions. Each engine must be tuned to obtain maximum results. Usually, a compromise has to be effected between emissions and performance, such as, when a dual fuel system is employed or when the ignition advance mechanism is removed to obtain lower emissions of oxides of nitrogen.

A. C.N.G.

CNG does not afford sufficient mileage to be used as an independent system. When coupled with gasoline, a compromise must be made in the tuning. The result is poor performance, loss of power and poor economy when operating on natural gas.

The excess weight of the tanks may render automobiles unstable at high speeds.

The cost of operating and maintaining this system is higher than for gasoline fueled vehicles.

B. L.N.G.

LNG may be used as an independent system, providing that the vehicle's tank has sufficient volume to furnish fuel for the necessary range. The scheduling of the vehicle must allow the vehicle to return to its home base for fueling, as this fuel is not available at outlying areas. As an independent system, natural gas results in the lowest exhaust emissions of any fuel tested.

The conversion cost to LNG is far greater than the other gaseous fuels mentioned in this report.

The estimated cost for a fueling facility is higher than the other fuels. Mr. Paul Hathaway of San Diego Gas and Electric estimates that a 10,000 gallon LNG tank will cost $40,000. The complete "closed fueling" system will cost approximately $175,000.

Present cost of LNG delivered to Los Angeles is between 18 and 20 cents a gallon, depending on the volume of fuel. Bulk LNG may be purchased at San Diego at 15 cents a gallon. The price of LNG may be reduced slightly when it becomes available in large quantities in the Los Angeles area. Therefore, it may be concluded that the cost of LNG in Los Angeles ranges from slightly below the cost of gasoline to a cent or two above.

The Arthur D. Little, Inc. Study states:

> Since 1968, natural gas consumption has exceeded the discoveries of new reserves in the "proved" classification. With demand increasing at more than 5% per year, the future of the natural gas industry is critically dependent on the discovery of new reserves. New discoveries cannot immediately relieve the situation, so natural gas will be in short supply throughout the decade and, particularly, in the mid-seventies.[1]

Arthur D. Little, Inc., as well as other studies, indicate that after 1975, improved supplies from Alaska and Canada, imported LNG and synthetic natural gas are only sufficient to keep pace with projected requirements.

In the event of a national emergency, foreign supplies of natural gas would be questionable and domestic supplies, undoubtedly, would be inadequate.

C. L.P.G.

LPG has been in use as a reliable vehicle fuel for over 40 years. It can compete with gasoline, but not diesel, relative to maintenance and operating costs. It is low emissions fuel, but with present technology, cannot meet the 1975 requirements. LPG tanks are available in various sizes and configurations so that, in most cases, they may be located outside of the trunk compartment of automobiles.

This fuel is available in most areas throughout Southern California. Vehicles operating on LPG could be fueled at public service stations in outlying areas.

VI. RECOMMENDATIONS

A. C.N.G.

The staff recommends the discontinuance of CNG in the Minibuses and that no further use of this fuel be considered, at this time.

B. L.N.G.

It is recommended, due to the high cost of conversion and of fueling facilities, that this fuel not be tested, at this time.

1. Arthur D. Little, Inc. Study, The Benefits and Risks Associated With Gaseous Fueled Vehicles, May 5, 1972, p. 40.

C. L.P.G.

It is recommended that Minibuses be converted from the dual fuel system of gasoline and CNG to LPG for the following reasons:

1. The low emissions characteristics of this fuel.
2. This fuel is available in the local areas.
3. Other agencies indicate that it is comparable to gasoline in performance and economy.

It is further recommended that consideration be given to the purchase of a fueling facility with an 18,000 gallon capacity tank. This facility could be amortized with the five cent savings in the cost of LPG in about 4 to 5 years.

It is also recommended that we do not test propane in any automobiles, at this time. Preliminary tests by the State of California indicate that low emissions gasoline fueled vehicles will be available by 1975.

The estimate purchase and installation cost of the LPG equipment for the Minibuses is $560 each.

The above conclusions and recommendations represent our opinions and judgments based on the technical data contained in this study. Much of the information was obtained through telephone conversations with knowledgeable people in the industry. Most of those contacted were very gracious and helpful. Only the personnel with the State of California were a little reticent to publicize their position relative to compressed natural gas.

George H. Wells
Deputy General Superintendent
of Maintenance and Equipment

Peter Drake
Operations Administrative Analyst

BIBLIOGRAPHIES

California Air Resources Board, Air Resources Laboratory, Emission Test on Three LP-Gas Vehicles, Project M-205, February 1970.

Shooter, Douglas and Kalelkar, Ashok, Arthur D. Little, Inc., The Benefits and Risks Associated With Gaseous Fueled Vehicles, May 5, 1972.

L.A. Times, December 27, 1972, p. 1, Sec. A

L.A. Times, January 16, 1973, p. 2, Part I

APPENDICES

APPENDIX A

ORGANIZATIONS CONTACTED

The assistance, information provided, and the courtesy extended to the Southern California Rapid Transit District by these organizations and numerous individuals within these organizations is gratefully acknowledged.

Manufacturers and Fleet Converters

Kaiser Brencar Enterprises
El Cajon, California

Dual Fuel Systems, Inc., A Subsidiary of Pacific Lighting Corp.
Monterey Park, California

Petrolane, Inc.
Los Angeles, California

San Diego Gas And Electric
San Diego, California

Fleet Operators

Certified Grocers
City of Commerce, California

Von's Market
El Monte, California

City, State and Federal Agencies

Los Angeles City, Transportation Department

Los Angeles County, Mechanical Department

Riverside County

Highway Department, State of California

General Services Administration, United States

APPENDIX B

EMISSION TEST ON
THREE LP-GAS VEHICLES

Project M 205

Three vehicles equipped with the LP-gas fuel system by Western Liquid Gas Association, Research and Development Committee, were delivered to the Air Resources Laboratory for emission test. They were a 1969 Chevrolet El Camino, a 1970 Chevrolet pick-up truck, and a 1965 Oldsmobile 4-door sedan.

All three vehicles were parked inside the laboratory for overnight soak before they were tested from a cold start on a Clayton chassis dynamometer. The emission tests were performed in accordance with the "California Test Procedures for Motor Vehicles Modified to use Liquefied Petroleum Gas or Natural Gas Fuel" adopted by the Air Resources Board in November 1969.

Each test vehicle was placed on the chassis dynamometer and driven through seven 7-mode cycles. The exhaust gases from each cycle were monitored by a NDIR sampling train for concentrations of hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and nitric oxide (NO). Exhaust gases from the last two cycles were collected in Mylar bags and analyzed by the subtractive techniques for reactivity.

The test data are summarized in the attached table. The emission values are lower than the 1974 California Emission Standards which are 1.5 gm/mile for HC, 23 gm/mile for CO, and 1.3 gm/mile for NO_x.

EXHAUST EMISSIONS

From Vehicles Equipped With LP-Gas Fuel System
by Western Liquid Gas Assn., R & D Committee

Test No.	Test Vehicle	License No.	Odometer Reading	Exhaust Emissions HC		CO		NO_x		Reactivity Units
				ppm	gm/mi	%	gm/mi	ppm	gm/mi	
1.	69 Chev. 8, 350, 4, A	85560B	23,875	44	0.56	0.12	2.86	116	0.45	85
2.	70 Chev. 8, 350, 4, A	568827	3,927	38	0.48	0.12	2.86	144	0.56	86
3.	65 Olds. 8, 425, 2, A	XIR 821	131,385	20	0.25	0.53	12.64	286	1.12	96

The above test data was compiled by the Air Resources Board Laboratory, State of California, and corrected per California Standards.

The above tests were coordinated by Western Liquid Gas Association, Research & Development Committee Subcommittee on Vehicle Exhaust Emission Tests.

APPENDIX B

State of California

AIR RESOURCES BOARD

Reduction of Air Pollution by the Use of
Natural Gas or Liquified Petroleum Gas Fuels
for Motor Vehicles

March 18, 1970

Basic Properties of Gas Fuels

Natural gas and liquified petroleum gas (L.P.G.) fuels are gases rather than liquid at normal atmospheric temperatures and pressures. This is in contrast to the usual fuel for motor vehicles, gasoline, which is liquid at normal temperatures. Natural gas and L.P.G. as commonly marketed are mostly methane and propane, respectively. Some physical properties are listed below:

	boiling point °F	heating value Btu/lb	Btu/gal.	liquid specific gravity
Gasoline	100	20,500	123,000	0.7
Methane	- 259	23,900	61,000	0.3
Propane	- 44	21,700	91,000	0.5

Note: Methane produces 100,000 Btu/100 cubic feet, which has been taken to roughly equal one gallon of gasoline.

Gaseous Fuel Conversions

Vehicles can be modified or "converted" to operate on Natural gas or L.P.G. Such a conversion comprises a carburetor, pressurized tank, pressure regulator, shutoff valve and lines. The special carburetor to handle the gaseous fuel must be carefully tailored to obtain low emission results. Low emissions will not result by making a conventional conversion to these fuels. This fact makes necessary approval of these special carburetors and modifications by the Air Resources Board. Some gaseous carburetors are designed to replace the gasoline carburetor and some are designed to add to it so that "dual-fuel" operation can be maintained. Such vehicles can then be operated on either the gaseous or gasoline fuel.

Emission Test Results

Shown in the table below are recent Air Resources Board's emission test results from three liquified petroleum vehicles and three natural gas vehicles adjusted for low emissions.

	vehicle		emissions in grams per mile		
fuel	make	year	HC	CO	NO_x
L.P.G.	Chevrolet	69	0.56	2.9	0.45
	Chevrolet	70	0.48	2.9	0.56
	Oldsmobile	65	0.25	12.6	1.1
Natural gas	Chevrolet	68	0.71	3.4	0.6
	Jeep	69	0.51	1.8	0.55
	Ford	69	0.82	4.5	0.48

Emission data from both systems show good potential for meeting 1975 standards. However, more data are needed to establish the capabilities of the systems when applied to a large population of vehicles. It is planned to continue State fleet emission tests on both systems.

APPENDIX C

September 28, 1971

Samuel Black

R. E. Huff

Natural Gas Refueling Estimates and Bid From Dual Fuel Systems, Inc.

Natural Gas Refueling Facility Estimate for 19 buses @ 1,243 c.f. of CNG each for a total of 23,617 c.f.:

Electric Compressors:		
Two 35 c.f.m. compressors installed	$ 8,700	
Meter set assembly	150	
Reducing regulator	160	
Piping manifold (20 outlets)	3,000	
Slow fill, 5.6 hrs. for 19 buses	$12,010	$900.74/mo.
Engine Compressor:		
100 c.f.m. rebuilt engine and compressor installed	$ 7,700	
Meter set assembly	150	
Reducing regulator	160	
Piping manifold (20 outlets)	3,000	
Slow fill, 3.8 hrs. for 19 buses	$11,010	$825.74/mo.
10,093 c.f. reservoir:	2,200	
Quick fill for 2.4 buses	$14,210	$1,065.75/mo.
23,750 c.f. reservoir:	7,635	
Quick fill for 6.3 buses	$19,645	$1,143.45/mo.

APPENDIX C

24,872 c.f. reservoir:	$ 5,620	
Quick fill for 6.1 buses	$17,630	$1,322.24/mo.
43,500 c.f. reservoir:	8,900	
Quick fill for 12.9 buses	$20,910	$400.00/mo

Natural Gas Refueling Facility Bid Price for 19 buses @ 1,898 c.f. CNG each for a total of 36,062 c.f.:

Electric Compressors:

Two 35 c.f.m. compressors installed	$ 8,700	
Meter Set Assembly	150	
Reducing regulator	160	
Slow fill, 8.5 hours for 19 buses:	$ 9,010	
79,199 c.f. reservoir:	44,341	
Quick fill for 20 buses	$53,351	$1,626.23/mo.

REH:jc

APPENDIX D

Use of smog-free propane gas fuel to operate 68 Riverside County-owned vehicles was ordered by supervisors despite a fire which destroyed a van vehicle last week in Blythe. Two county employes suffered burns in the fire, believed to have been touched off by a cigaret when LPG gas fumes escaped because of faulty fueling. After the fire, the county's car pool superintendent asked that the fleet be reconverted to operate on gasoline. Instead, supervisors ordered that each vehicle be certified as safe before being put into operation and that smoking be prohibited in or near the vehicles.

L.A. TIMES
DEC. 27, 1972
PG 1, SEC. A.

APPENDIX E

★ Los Angeles Times Page 2, Part 1

Inside The Times

News in Brief

TUESDAY, JANUARY 16, 1973

Compiled from the Los Angeles Times, the Los Angeles Times-Washington Post News Service and major wire and supplementary news agencies.

An experimental car exploded and burned in a federal government parking lot in San Diego when leaking natural gas used as fuel as a means to reduce air pollution was ignited, presumably from a spark when the driver turned on the ignition switch. Jose M. Parragah, 23, who was burned on the hands and face, escaped from the vehicle by climbing through a broken window. The blast occurred in the General Service Administration's lot.

RTD 37-11
REV. 3/65

DEPARTMENTAL

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

1060 SOUTH BROADWAY
LOS ANGELES

DO NOT INCLUDE MORE THAN ONE SUBJECT IN THIS COMMUNICATION

DATE: January 3, 1973

TO: Mr. George H. Powell

FROM: George H. Wells

SUBJECT: Propane/Equipment Suppliers

In accordance with your request, I contacted the following by telephone on Wednesday, January 3, 1973:

Manchester Tank and Equipment Company
Robert Reifschneider, Executive Vice President

Mr. Reifschneider said that he had had a meeting with the District officials, including Mr. Gilstrap, and that one of the items discussed was the possibility of equipping a large bus to operate on propane. He thought this could be a similar program as was conducted with the Pacific Lighting Corporation. He also indicated that, if this program was a success, it would be a great asset to the propane industry.

Petrolane Incorporated
Tom Laubach

Mr. Laubach stated that he was working on the big bus project and that he had contacted Waukesha relative to the use of a large V-8 diesel engine converted to operate on propane. This V-8 engine has sufficient horsepower and can be operated at governed speeds up to 2,300 RPM.

Mr. Laubach indicated that this particular engine had been used in large trucks, but is no longer used except for stationary power plants, etc.

He further stated that, economically, there is no comparison between propane and the diesel engine.

RECEIVED
JAN 4 1973
G.W.H.

GEORGE H. WELLS
Deputy General Superintendent
of Maintenance and Equipment

GHW:ki

cc: G.W. Heinle

ALTERNATE FUELS STUDY

RTD 37-11
REV. 3/65

DEPARTMENTAL

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT

1060 SOUTH BROADWAY
LOS ANGELES

DO NOT INCLUDE MORE THAN ONE SUBJECT IN THIS COMMUNICATION

DATE: December 19, 1972

TO: Richard Gallagher, Chief Engineer

FROM: Don Gardner, Senior Engineer

SUBJECT: VISIT TO ELECTRO-BUS FACILITY IN VAN NUYS

In response to George Heinle's request to Sam Black, yesterday Pete Drake and I visited the Electro-Bus Company in Van Nuys and inspected their vehicle in detail. This is the same bus that was demonstrated in front of the District building early in December. We talked to Mr. H. H. Flumm, Vice President of Marketing and Mr. B. Borisoff, Vice President of Engineering. You are familiar with the vehicle itself and the fiberglass construction, door operations, seating, etc., so I will confine most of my remarks to the electrical system. Pete Drake made a record of most of the operating characteristics, as a vehicle, which together with these comments should give a good appraisal of our overall inspection.

Basically, the drive consists of a direct-connected 50HP D.C. motor directly connected through a Rockwell differential to the rear wheels. The mechanical construction is adequate and I think it is properly designed for the application. Power is supplied from a huge dual 36-72 volt series/parallel battery through heavy duty contactors to the motor. The contactors are controlled from a master control unit at the drivers station actuated by a foot pedal. The contactor assembly is located in a cabinet under the rear seat between the battery and the motor and only control wires are required to the drivers compartment. All of the parts are designed in-house except for two or three small control relays.

The designers claim that they have experienced no failures, to date, in the electric system; however, I believe that some of the components, in time, will begin to evidence deterioration. All of the controls operate from a typical 12 volt heavy duty bus battery independent of the traction battery but charged from it through a motor-alternator.

RECEIVED
JAN 11 1973
G.W.H.

Improvements that can be expected to up-grade the vehicle design are in my opinion significant, but it would be improper to suggest these to the Electro-Bus people without handing over to them the results of designs developed by other companies. Therefore, these comments should be held in confidence and are listed below:

1. The main contactor circuit breaking fingers are mounted horizontally. Common practice is to arrange them vertically so that foreign matter, dirt, chips, etc. cannot accumulate on the contact surfaces and deteriorate performance. Since the heat from any arcing rises vertically, this likewise would escape in a vertical arrangement, without causing damage, and arc chutes to absorb the arc could be readily added. The contactors are of rugged design and appear to operate freely but will, in time, probably cause problems. Several small relays are mounted in the same control cabinet, which obviously are not heavy duty units normally associated with traction control equipment.

2. The master controller consists of a machined cam sequentially operating 8 small roller arm microswitches. These are assembled in a way where the model number could not be read but are typically the V-8 series found in coin operated machines, etc. I would prefer to see a small drum controller master unit electrically equivalent but mechanically more rugged. The space required for such a unit would not be materially increased.

3. Control wiring in some instances was made up of rather small wires which are electrically adequate. In transit work, however, the designer must keep in mind the mechanical stresses imposed and I would prefer to see a well made wiring harness made up of at least heavy duty automotive wire if not typical traction control wire.

4. The reverse latch assembly was mechanically positive in operation but the operating coil for the latch release was very small and again not designed around traction parameters.

The cost of the vehicle was around $28,000, less the battery. The Electro-Bus people contend that the battery is an expense item and its $4,000 cost should not be capitalized; however, an objective appraisal must consider the battery as a fuel tank since it is, in reality, filled and drained by useage like any other energy container on a vehicle. Therefore, in our opinion the cost of the vehicle should be $32,000.

It is Pete Drake's intent to visit the Long Beach area in the near future and witness the operation of this vehicle as it initiates a demonstration period of several days, during which time he will have the opportunity to observe the traction battery replacement operation. The time required will be of great interest since to a large degree this will determine the degree of practicability offered by this particular vehicle.

In summary, in my opinion, the Electro-Bus designers have come a long way in bringing their vehicle to its present state of development without governmental funding. The remaining development which I have suggested above should be quite evident to them before too long. I believe that the District should withhold any immediate commitments to use their vehicle but encourage them to continue improving the electrical design. Then in two or three years, assuming that said improvements have been incorporated, the feasibility of a trial operation of one or more vehicles could be safely recommended. If the District feels that an earlier trial should be considered, then by all means, direct suggestions for specific improvements to Electro-Bus should be proposed.

— why not for a trial in town (L.B. is purchasing 2 to try & we can watch them) (Rec'd DG 1/10)

DG/da

cc: S. Black
P. Drake
G. Heinle
G. Powell