Liquefied Petroleum Gas as a Motor Vehicle Fuel

Report

This Report is one of two that have been prepared in the BTE to review the state of knowledge in the field of alternative road vehicle technologies and to indicate the magnitude of possible benefits (the other being a report on electric cars).

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BUREAU OF TRANSPORT ECONOMICS

LIQUEFIED PETROLEUM GAS AS A MOTOR VEHICLE FUEL

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FOREWORD

In recent years it has become clear that the community will not accept the continually rising levels of air pollution being caused by motor vehicles. One way of tackling the problem is to introduce alternative road vehicle technologies; some of these alternatives also offer potential gains in terms of energy resources. This report is one of two that have been prepared in the BTE to review the state of knowledge in this field and to indicate the magnitude of possible benefits (the other being a report on electric cars).

This report, dealing with liquefied petroleum gas, has been prepared by Mr L. Lawlor.

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SUMMARY

Estimated Australian reserves of liquefied petroleum gas (LPG) are sufficient for 80 years supply at the present rate of extraction. If used within Australia this would permit a maximum of 14 per cent of motor vehicles to be converted to LPG.

The considerable Australian reserves of LPG offer some scope for increased consumption by motor vehicles. However, distribution installations and vehicle mounted equipment are expensive.

LPG engines have operational characteristics broadly comparable to petrol and diesel engines and can be tuned to produce significantly lower levels of pollutants. However, tuning to minimise pollution is incompatible with tuning for maximum power and economy, so the practical effects of a wider use of LPG in urban motor vehicles may not be great.

Examination of the value of converting existing engines to LPG at present prices shows that most truck and car owners in Melbourne would benefit financially. In Sydney, heavy truck operators and car owners travelling large annual distances would benefit. In each city, State and Local Government authorities would also benefit, but to a lesser extent.

Users would only obtain these benefits if LPG were to continue free of excise. Should an excise be imposed, LPG would cease to be competitive with petrol.

From the general social viewpoint, there is not a strong case for substantial conversion to LPG; the case rests mainly on some reduction in air pollution, but there has been insufficient measurement to establish the magnitude of this benefit.

CHAPTER 1 INTRODUCTION

In Australia, as in most other advanced countries, the level of pollution in major cities, much of it associated with motor vehicles, is a matter of serious concern. There are many ways of improving the situation, and well substantiated advice is required on the implications of various measures. One possible measure would be the increased use of liquefied petroleum gas (LPG) as a substitute for petrol.

Consideration of expanded use of LPG must necessarily take some account of the implications for fossil fuel resources, which itself is a matter of considerable public concern. Hence this report deals with fuel supply, demand and pricing so far as these are immediately relevant to the merits of LPG as a vehicle fuel.

LPG has been used overseas as an alternative fuel for many years, although on a small scale. However, there is a lack of authoritative information on the relative engineering and pollution characteristics of LPG and petrol.

The report examines the costs and benefits which may be expected from conversion from petrol to LPG, first from the user's viewpoint and then from the viewpoint of the nation as a whole. In particular, the performances of petrol and diesel engines converted to LPG are examined to assess differences between engines in terms of power and emissions.

Annexes D and E present tabulations of break-even calculations for private, commercial and government operators over a wide range of possible variations in LPG usage, fuel costs, engine size and annual travel distance. These have been made for various categories of motor vehicle.

The report also investigates the possible effects of extensive use of LPG by vehicles in capital cities. Particular attention is given to increased investment in bulk storage facilities, transport equipment, retail outlets and vehicle mounted conversion equipment.

CHAPTER 2 LIQUEFIED PETROLEUM GAS

DESCRIPTION

Hydrocarbon gases associated with petroleum in its crude state range in composition from pure hydrogen to heavier hydrocarbons which are only partially vapourized at ambient temperature and atmospheric pressure. A similar variety of gases also results from the processing of crude oil or petroleum fractions in refineries. Hydrocarbon gases may also be manufactured specifically from liquid hydrocarbons[1].

The term LPG is generally used to describe petroleum derived hydrocarbons which are vapours at normal temperatures and pressures, but which may be liquefied by light compression to occupy a much smaller volume. The main constituents are propane and butane, but the composition varies with the source. Where obtained from an oil or gas field, LPG does not contain propylene or butylene, but LPG produced by refining crude oil may contain both of these.

The presence of more than about 5 percent of propylene and/or butylene in LPG renders it unsuitable for automotive use. Further, LPG for motor vehicles must be of reasonably constant composition, since the fuel mixing device (analogous to the carburettor) in a gas engine is designed to mix fuel and air in a set volume ratio. LPG suitable for automotive use contains a high percentage of propane, generally 95 percent or more. The physical properties of propane are compared with those of motor spirit (98 octane) in Table 1.

In Europe, LPG is generally obtained from petroleum refining operations, while in North America the bulk of LPG is derived from natural gas liquids. This has resulted in the two distinct LPG consumption patterns indicated in Table 2, which shows

(1) Modern Petroleum Technology, Applied Science Publishers (UK) 1973. Chapter 13.

that in Europe its use as a domestic fuel and gas industry feedstock has far exceeded its chemical utilization, while in North America LPG is largely used for domestic heating and as a chemical feedstock.

PRODUCTION AND CONSUMPTION

In Australia, most of the LPG is obtained in association with crude oil and natural gas from Bass Strait and other gas fields, while the remainder is a by-product of oil-refining operations. The LPG derived from natural gas can be regarded as a by-product of the process of supplying dry natural gas (i.e. gas excluding the easily liquefied hydrocarbons) to metropolitan and other gas distribution systems.

The bulk of the LPG produced in Australia (as a direct result of natural gas and crude oil production) is exported to Japan. In 1972-73 a total of 10.52 million barrels (872,000 tonnes) was exported; this represented 72 percent of total Australian extraction. Australian refineries produce LPG in the normal course of their operations. In 1972-73 LPG produced in this manner was 3.99 million barrels (331,000 tonnes) equivalent to 95 percent of Australian consumption for the year, and 1.5 percent by weight of total marketable refinery products out-turned during the period.

Table 3 shows the growth over the last few years of the Australian market for LPG[1]. The major Australian use is for domestic heating, small portable heating appliances, industrial heating, and metal cutting, with some limited automotive applications in fork lift trucks (where high emissions of carbon monoxide are a hazard) and for cars and trucks.

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(1) Fuels Branch, Department of Minerals and Energy, Australian Petroleum Statistics, 1972-73.

MARKETING AND DISTRIBUTION

The marketing of LPG in Australia is characterised by a small number of primary outlets, which serve major users with a significant storage capacity of their own, and a very large number of small capacity secondary outlets, which serve low volume users such as caravanners. Even for relatively large users the supply arrangements for LPG are not entirely satisfactory. This was brought out in evidence provided in 1971 to the Senate Standing Committee on Primary Industry and Trade[1]. The conclusions of the Senate Committee (Annex A) drew particular attention to the problems of shortages and higher costs as a result of refinery shut-downs, inadequate storage facilities and the variability of consumption and production.

It was announced in 1973 that the Broken Hill Proprietary Company Ltd and the Shell Company Australia Ltd were forming a company, Shell-BHP Autogas Pty Ltd, to market LPG for automotive use[2]. Present plans are understood to include 24 reseller sites in Victoria, and a lesser number in New South Wales. Other oil companies and state gas authorities can provide LPG for automotive use through a smaller number of outlets.

AUSTRALIAN RESOURCES

A preliminary assessment of the level of Australian LPG reserves is set out in Table 4. The quantities shown may be taken as a reasonable estimate of the current reserves in the 'proved plus provable' category, which represents the gas directly recoverable from the oil and gas resevoirs which have been discovered to date.

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(1) Senate Standing Committee on Primary and Secondary Industry and Trade, Report on Availability of Liquefied Petroleum Gas, December 1971.

(2) The Australian Financial Review, 31 July 1973.

The total reserves of 1,133 million barrels (equivalent to 94 million tonnes of LPG) represent 80 years supply at the 1972-73 rate of extraction. Australian consumption of LPG could rise to more than three times its present level before equalling the 1972-73 total of LPG produced from refineries and in association with natural gas extraction.

At present the level of market demand for major petroleum products determines the volume of natural gas production and the composition of refinery output. The quantity of LPG produced as a by-product of these operations is variable and not subject to direct control. Because LPG production exceeds domestic consumption the surplus is exported, but an alternative course would be to pump the excess back into the natural resevoirs. However, this has a cost and pursuing such a policy would imply a very high future value for the LPG.

FUTURE TRENDS IN CONSUMPTION

The Fuels Branch of the Department of Minerals and Energy has issued a forecast of energy consumption of primary fuels over the period to 1984-85, which shows a 71 percent increase in domestic LPG consumption, from 4.03 million barrels in 1973-74 to 6.88 million barrels in 1984-85. This represents an expected growth rate of 5 percent per annum over the period[(1)].

These estimates have been based on the assumption that the rising trend in LPG consumption of the last few years will level out over the forecast period, and that reticulated natural gas will displace the LPG currently used for town gas supply from 1975 onwards. No provision has been made in these estimates for large scale automotive consumption of LPG. The estimates are based on a total Australian energy forecast of a 72 percent increase in total petroleum fuel consumption between 1973-74 and 1984-85.

(1) Fuels Branch, Department of Minerals and Energy, Forecast Consumption of Primary Fuels, 1972-73 to 1984-85.

STORAGE

LPG is stored and transported as a liquid, liquefaction being achieved by either compression or refrigeration. Storage vessels are either thick walled steel spheres or cylinders, which have a design pressure of 1760 kPa (255 psi) and are built to a test pressure of 3310 kPa (480 psi), or insulated steel or aluminium containers, located either above ground or in the ground, and which maintain a temperature of about minus 45°C.

LPG is transported by pipelines, or by road or rail in tank cars, and is pressurised to maintain it in the liquid state at the highest ambient temperatures likely to be encountered. It is carried in specially equipped ships as a refrigerated liquid at atmospheric pressure.

State legislation generally covers the storage and handling of LPG. Pressure vessel codes apply to the design and construction of storage vessels and inflammable liquids legislation generally covers the siting and safety aspects of storage tank installation. The Standards Association of Australia has issued two Standards relating to the use of LPG[1,2].

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(1) SAA Code for the use of Liquefied Petroleum gas in internal combustion engines, No. 1425/ 1973, SAA, 1973.

(2) SAA Liquefied Petroleum Gas Code, No. CB 20/1971, SAA, 1971.

CHAPTER 3 OPERATIONAL CHARACTERISTICS

PETROL ENGINES - OPERATION ON LPG

Fuel Supply

LPG can replace super grade (98 octane) or standard grade (89 octane) petrol as the sole fuel in an internal combustion engine; these engines can be equipped to run alternatively on LPG or petrol, or on LPG only. Equipment for the LPG operation of petrol engines consists of a storage tank for the liquid, fuel lock valve, pressure regulator and a gas-air mixing device on the intake manifold.

The original carburettor is removed for operation solely on LPG and is replaced by the gas-air mixer. In operation, the LPG fuel system draws liquid from the tank by means of a valve in the gas-air mixer which is controlled by the driver, and passes it through a vacuum fuel lock which prevents the flow of fuel when the engine stops. The liquid is then heated by coolant water in a liquid-to-gas converter which regulates the outlet gas pressure in accordance with engine demand. The gas-air mixer measures air flow and meters the flow of gas into the engine air stream to provide a uniform air-fuel mixture over the entire engine and speed range. A schematic diagram of a typical system is shown in Figure 1.

During the LPG operation the mixture fed to all cylinders of an LPG engine is entirely gaseous, as distinct from the use of petrol where a mist of air, vapour, and liquid droplets is fed to the engine. In the latter case, the composition of the mixture varies due to deposition and revaporization of liquid in the inlet manifold. Consequently, an LPG engine may be operated with a leaner fuel-air mixture than is used for a petrol engine.

In the case of dual-fuel operation the original carburettor is retained, the gaseous LPG is injected between the carburettor and the air intake filter through a gas-air mixer, and a control is provided to change from petrol to LPG operation.

Engine Peformance

Tests have been carried out in the United States on petrol engines converted to LPG operation[1]. The tests covered economy, performance, compression ratios and anti-knock quality in three test engines. The engines were a V6 of 7.8 litres capacity and compression ratio of 7.3, a V8 of 9.0 litres capacity and compression ratio of 8.5, and a V8 of 6.8 litres and a compression ratio which was variable from 7.5 to 11.5. Some of the conclusions are as follows:

1. At a given compression ratio and using currently available vapourizers and carburettors, the engines developed 3.5 to 5 percent less power on LPG than on petrol, at high engine speeds.

2. Compared to petrol, the use of LPG reduced brake specific fuel consumption (lb/bhp hr) by up to 12 percent at low speeds. At high speeds, LPG reduced fuel consumption by up to 9 percent. On a gallon basis, however, the engine uses more LPG than petrol because of the lower specific weight of LPG.

3. In two engines with compression ratios of 7.3 and 7.5, the LPG selected for the program had anti-knock values far in excess of engine requirements. Therefore the compression ratios could have been increased.

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(1) Adams, W.E. and Boldt, K. 'What Engines say about Propane Fuel Mixtures', Paper 938 C, SAE National Transportation, Powerplant and Lubricants Meeting (USA), October 1964.

4. As the compression ratio of one engine was increased from 7.5 to 11.5, power increased 12 percent and brake specific fuel consumption decreased 11 percent when using LPG. Approximately the same changes were noted when using petrol.

5. One engine showed essentially no difference in the minimum spark advance for best torque between LPG and gasoline. The other two engines showed some difference between the two fuels. Where a difference existed, the engines required less spark advance on LPG at high speeds.

6. In order to take full advantage of the high anti-knock quality of LPG, it is important to keep intake air temperatures as low as possible. Knock-limited spark advance was lowered one degree for each 5.5°C rise in intake air temperature in the range of 38 to 79°C.

These tests were carried out with manifold heat exchangers blocked when operating on LPG.

The power loss at high speed with LPG is caused by the fact that LPG enters the airstream as vapour, while petrol enters as a liquid. The LPG vapour displaces an equal volume of the air entering the cylinder. As the mixture is made richer for higher power output the additional fuel causes a power loss because the airflow is reduced.

The conditions for a liquid fuel, such as petrol, are quite different. Liquid fuel takes the latent heat of vapourization from the airstream. As the fuel-air ratio is enriched for maximum power, the additional fuel being vapourized tends to lower the mixture temperature, thereby increasing the air density. The fuel that is not vapourized enters the combustion chamber as a liquid, thereby displacing very little air. The combined effect of these two factors is that there is little change in airflow.

Thus, while the energy content of a cubic foot of homogeneous mixture is constant for a wide variety of hydrocarbons, the temperature of the charge and the amount of entrained liquid both tend to change the energy content on a volume basis. As mixtures are enriched beyond the fuel-air ratio for best torque, the power output with LPG will continue to decline, whereas for petrol, power output will remain nearly constant for a wide range of fuel-air ratios.

DIESEL ENGINES - OPERATION ON LPG

LPG cannot serve as the sole fuel for diesel engines unless they are considerably modified. The compression ratio, cylinder head and fuel injection system must be completely changed. Diesel engines can be rebuilt or designed solely for LPG operation.

One conversion method which has been used is to reduce the compression ratio, increase the displacement, remove the fuel injection equipment and install spark plugs so that LPG may be injected in the induction manifold. This method has been employed by Daimler-Benz in a recent experimental bus utilizing natural gas. The engine, although using components common to other Daimler-Benz diesel engines, was designed specifically for natural gas and it appears to be a high compression, spark ignition engine rather than a diesel engine(1).

There are two methods of introducing LPG into distillate-fuelled diesel engines(2). Introducing gas throughout the entire load range is described as 'coarse control', whereas if it enters the engine only under heavy load, it is described as 'fine control'.

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(1) Communications with Dr Kraeft, Daimler-Benz Aktiengesellschaft, Stuttgart, F.R. Germany.

(2) Lyon, D., Howland, A.H., and Lom, W.L., 'Controlling Exhaust Emissions from a Diesel Engine by LPG Dual Fuelling'; Paper C 126/71, Symposium arranged by the Automobile Division and The Combustion Engines Group, Institution of Mechanical Engineers, London, 9th-11th November 1971.

A typical 'fine control' system consists of a storage tank, pressure regulator, flow control valve and an exhaust gas temperature sensor. In operation, the LPG is drawn from the tank, piped to the regulator and warmed by engine cooling water. This vapourises the liquid in readiness for induction into the engine air intake system. Liquid flows into the regulator through the action of a thermal switch installed in the exhaust manifold which operates at a present exhaust temperature. A decrease in exhaust gas temperature will open the switch and stop the flow of liquid from the storage tank.

The regulator delivers gaseous fuel to the engine intake manifold at 28 kPa (4 psi) and the amount of fuel is determined by the depression in intake manifold pressure. At high load, the added amount of LPG fuel is a function of driver demand for extra power.

The air-fuel ratio within the intake manifold and cylinders is too high to cause compression-ignition of the air-LPG mixture prior to injection of the diesel fuel charge.

Engine Performance

Fuel consumption under coarse control is less efficient under part load conditions than when operating with distillate only. Dual fuelling using the fine control method makes it possible to obtain fuel efficiency improvements under heavy load while avoiding the poor efficiency of coarse control under light load.

Dual fuel operation can be effected in two ways. Under one system, the maximum diesel fuel supply is reduced by 25 per cent, and the LPG is allowed to enter the air supply in proportions necessary to restore the original power. The purpose of this approach is to reduce smoke and exhaust emissions. Alternatively, LPG can simply be added to the normal diesel fuel supply, in which case there is an increase in the maximum power output of the engine.

CHAPTER 4 ECONOMICS OF CONVERSION: THE USERS' VIEWPOINT

From the user's viewpoint, the following economic considerations are relevant in choosing between LPG and conventional fuels:

(i) cost of conversion to LPG
(ii) comparative fuel costs
(iii) comparative engine and fuel systems maintenance costs
(iv) comparative engine and equipment salvage value

CONVERSION COSTS

Conversion costs are affected by the volume of conversion work. Typical conversion costs at the present time range from about $400 to $600 per vehicle.

The variables which affect the cost of conversion include the size and number of fuel tanks, the length of manifold, the capacities of the fuel lock, liquid-to-gas converter and gas-air mixer, and whether or not dual-fuel operation is required. The physical layout of the vehicle itself will affect the ease with which the installation can be carried out.

It is anticipated that vehicle mounted LPG equipment will have a long life. A period of 20 years has been assumed in one American study(1). When selling LPG powered vehicles, owners would be able to restore the original petrol equipment and fit the LPG equipment to another vehicle at small cost.

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(1) Carson, C., Operating Experience with Trucks and Automobiles Fuelled with Propane, ASTM Special Technical Publication 525, American Society for Testing and Materials, 1973.

FUEL COSTS

Because of the need for expensive static and mobile facilities for the storage and transport of LPG, its cost is dependent on the distance from the distribution point. Current retail prices are about 21 cents per gallon in Melbourne, 22 cents per gallon in Adelaide and 31 cents per gallon in Sydney.

The retail price will be higher in inland areas. In Canberra, for example, it is expected that transport costs of 10 cents and storage costs of 2 cents would be added to the Melbourne price. The range of discounts offered to various classes of LPG users is much narrower than for motor spirit, probably because LPG is mainly sold to bulk users through a much smaller number of outlets.

Melbourne retail prices of petrol, LPG and distillate, per unit of energy ($ per megajoule) are compared in Table 5. In these terms, LPG fuel cost is 64 per cent of distillate cost, and just over half the cost of premium petrol. Since available data suggests that on a volume basis, the fuel consumption of vehicles operating on LPG is at least 10 per cent higher than for vehicles operating on petrol or distillate, the effective saving to operators is correspondingly less.

Furthermore, as can be seen from Table 5, the cost advantage held by LPG over motor spirit and diesel fuel is almost entirely due to the absence of excise duty on the sale of LPG. This situation could change in the future, especially if LPG becomes a more extensively used motor fuel.

In considering the effective cost of LPG to the user, it is important to recognise that distribution points are at present very restricted compared to petrol outlets. While it is unlikely that the multiplicity of petrol outlets is an economic optimum, nevertheless, there would have to be a considerable number of LPG distribution points if major inconvenience to users were to be avoided. In some cases, it may not even be practicable to distribute LPG through existing service stations because of safety regulations which govern the distance of LPG storage tanks from property boundaries. The cost of investment in new or extended retail outlets would ultimately fall on consumers.

It has been assumed that individual sales of LPG would be comparable to present motor spirit sales, with consumers purchasing small quantities at frequent intervals. On the other hand, if LPG use were confined to bulk users with their own or hired storage, the need for a large number of reseller sites would not arise.

MAINTENANCE COSTS

There is insufficient experience to permit an accurate estimate to be made of improvements in the maintenance and life of equipment converted to LPG operation. Annex B summarises the experience of several operators of LPG powered vehicles. (Maintenance data are only available for one of these users).

Some users, as well as several conversion equipment manufacturers, have claimed reduced maintenance costs and increased engine life with LPG operation. As both maintenance and engine life are strongly affected by specific maintenance procedures and standards, it is not possible to quantify these claims except by reference to particular cases.

The maintenance advantages which have been claimed[1] are as follows:

. no fuel pump
. no fuel pilferage
. increased spark plug life
. reduced cylinder ring and valve wear
. increased lubricating oil life

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(1) Sagasco Autogas News, Issues No. 1 and No. 2, South Australian Gas Company.

- reduced carburettor maintenance
- increased engine life

The reasons given for these advantages are:

- negligible gum and carbon deposits
- no oil dilution or contamination
- improved upper cylinder lubrication
- smoother and slower burning fuel

On the other hand, a major supplier[(1)] of conversion equipment states that there are certain maintenance costs associated with the use of LPG, particularly if engines are adjusted to obtain minimum exhaust emissions:

- Increases in the heat range of spark plugs decrease hydrocarbon emissions, but also decrease plug life.
- A wider spark plug gap decreases HC emissions, but also decreases plug life and degrades starting performance.
- Valve seat wear increases with the use of LPG. It is best to use stellite seats and special hard valves.

WEIGHT PENALTY

Details of the weight of LPG fuel tanks are set out in Table 6. The majority of vehicles converted to LPG operation retain their petrol tanks after conversion. In passenger cars, these tanks are usually retained to permit dual fuel operation and ready conversion back to the original condition for resale, when the LPG equipment would be removed. Most trucks provide sufficient space for mounting the LPG tanks without removing existing petrol tanks.

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(1) Brooklands-Machins Pty Ltd; various marketing reports and operational manuals, Australia.

Passenger cars would usually retain the petrol carburettor, while most trucks would have this item removed since they would operate on LPG only. Thus the weight of LPG equipment would be in most cases an addition to vehicle weight.

Assuming a nominal passenger vehicle weight of 1.5 tonnes, Table 6 shows that an average fuel tank would represent an additional 2 percent in vehicle weight. With the variations in engine size and in vehicle shape and length, the weight of the gas-air mixer and ancillary equipment, the manifolding and the mounting brackets would comprise a variable but small weight. The extra weight of the LPG equipment would be offset to a limited extent by the lower density of LPG fuel.

BREAK-EVEN POINTS FOR CONVERSION

To investigate the savings to owners of petrol vehicles converted to LPG, calculations were made to relate the present value of future fuel savings to the cost of conversion. (No other costs or benefits were considered).

The parametric model, which is described in detail in Annex C, covers four user categories (general public, medium transport operators, State and Local Government, and Australian Government), based on the relative prices paid for petrol. Vehicles are divided into light vehicles (Category A), trucks under 4 tons carrying capacity (Category B) and trucks in excess of that capacity (Category C)[1]. Two different prices for LPG are incorporated (representing in this case Sydney and Melbourne prices) and one petrol price for each user category.

The results are in two parts:

- break-even annual distances for alternative fuel consumption rates; and
- break-even petrol-LPG price differentials for specified annual distances travelled per vehicle.

(1) These categories were derived from the Survey of Motor Vehicle Usage, Australian Bureau of Statistics, 1971, which used imperial units of capacity.

As far as the first set of results is concerned, the calculations set out in Annex D contain data for the 144 sets of parameter combinations for vehicles of average fuel consumption. One set of fuel cost differentials has been extracted and plotted graphically in Figure 2. These show the current situation, with the actual cost differentials applicable to the various user categories. Only three of the four user categories are shown, as there are no break-even distances for the Australian Government [1].

The break-even calculations are presented for each vehicle category, with separate graphs for Sydney and Melbourne LPG prices. The fact that the plots for each vehicle category on any given graph do not coincide shows the differential effect of the higher conversion cost of vehicles in Categories B and C and the increased fuel savings due to the higher fuel consumption associated with these vehicle categories.

Within a category the break-even distance is sensitive to the period of calculation (i.e. the assumed vehicle life remaining after conversion) and the discount rate.

Taking the three graphs for Melbourne together, it can be seen that the break-even distance is least for the general public and greatest for the State and Local Government categories for a given combination of parameters. This is due to the greater price differential applicable to the general public.

Comparing the graphs for Melbourne with those for Sydney, it can be seen that the break-even distance will be greater in Sydney, for a particular category of vehicle, due to the smaller fuel cost differential.

The graphs for each category may be extended in either direction to obtain data for vehicles with higher or lower than average petrol consumption.

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(1) The present price margin in favour of LPG is due entirely to the excise tax on petrol, which the Australian Government does not pay.

Turning to the break-even fuel cost differential results, three graphs are presented in Figure 3 for the State and Local Government owner category, for the average petrol consumption of each vehicle type. On any one graph it will be seen that the greatest cost differential for a given annual travel distance is associated with the combination of higher discount rate and shorter period of time.

Results for three levels of fuel consumption for each vehicle type are shown in Annex E.

Taking vehicles of average fuel consumption only, vehicles of Category C break even at a lower cost differential than vehicles of Categories A and B at any travel distance.

For similar vehicles with the same fuel consumption, break-even cost differentials for a given annual travel distance for the general public and medium transport operators are respectively 1.5 and 0.5 cents per gallon (0.3 and 0.1 cents per litre) greater than for the State and Local Government category. For the Australian Government, the differential is 2 cents per gallon (0.4 cents per litre) less. Thus the graphs for the State and Local Government cost differentials can be used to read off the differentials for the other three owner categories.

Based on the current price paid for petrol, a differential of at least 2 cents per gallon (0.4 cents per litre) is necessary for Australian Government vehicles to show break-even distances of under 70,000 kilometres per annum; this differential would only justify conversion of the heaviest trucks owned by the Government.

To sum up, on the basis of present fuel price differentials, the calculations suggest that for almost all privately owned vehicles in the Melbourne metropolitan area, it would pay the owners to convert to LPG. Heavy trucks would break even by travelling 3,000 km a year for approximately 6 years, while for light passenger cars, the distance would be 17,000 km a year for the same period. For medium transport operators and State and Local Governments, the annual distance for heavy trucks would be 4,000 km, and 25,000 km for light passenger cars.

In Sydney the break-even distance for heavy trucks is between 5,000 and 10,000 km per year for the different owner categories. For light passenger cars the distance to break-even over 6 years ranges from 27,000 km for the general public to 58,000 km for State and Local Governments.

CHAPTER 5 ECONOMICS OF CONVERSION: THE NATIONAL VIEWPOINT

The conclusions presented in the preceding chapter relate to the economics of conversion on the basis of relative fuel prices now confronting the user. However, these prices do not reflect the true cost to the nation of consuming one fuel rather than another, because:

- petrol and distillate prices include an excise tax, which is currently not levied on LPG;
- relative fuel prices, even before excise, are not freely determined in the market (that is, they are administered); and
- relative fuel prices do not reflect the 'external costs' associated with their consumption, particularly the effects of atmospheric pollution.

PRICES

Although the retail cost of LPG per unit of energy is substantially cheaper than petrol and distillate, Table 5 shows that this is entirely due to the fact that the latter fuels attract an excise tax whereas LPG does not at present. In fact, the comparison of wholesale prices before excise shows that, as at October 1973, LPG was marginally more expensive than premium grade petrol and substantially dearer than standard grade petrol and distillate. On the other hand, if most Australian LPG were to be consumed domestically, the price (before excise) would presumably be lowered, to replace the apparent policy of obtaining a relatively high unit return from a small volume of domestic sales and a lower unit return from a greater volume of exports.

EXHAUST EMISSIONS

A severe external or social cost of using motor vehicles arises from the effects of exhaust emissions. Using LPG is one means of reducing the atmospheric pollution that results from these emissions.

Because of the difference in the methods used to specify emission test procedures, there is no direct way of comparing the petrol, diesel and LPG engines. Furthermore, some published reports provide widely differing results in spite of the fact that the tests were conducted in the same manner. For these reasons, the data presented in this report should be treated as only a qualitative expression of the emission reduction that could be expected from LPG.

Comparisons of Petrol Engines with Propane and Natural Gas Engines

An extensive series of tests has been carried out by the Automobile Club of Southern California[(1)]. Road service vehicles converted to use either LPG only, or to use both LPG and petrol, were compared for a range of operational parameters with a control group of petrol powered vehicles. Apart from one Dodge Coronet (5.2 litre engine) all the test vehicles were Ford Rancheros (4.9 litre engines) of model years 1969, 1970 or 1971.

The vehicles were tested through the California Seven Mode Cycle on a chassis dynamometer. Sufficient data were obtained at four mileage intervals to provide the information presented in Tables 7 and 8.

Compared to petrol powered engines, emissions from LPG engines are much lower, especially in carbon monoxide (CO) content. CO levels are a little higher for LPG in dual fuel engines than for LPG in single fuel engines, due to the need for a slightly richer mixture for good idling. Dual fuel operation, however, produces less unburned hydrocarbons (HC) and nitrogen oxides (NO_x) than LPG single fuel operation.

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(1) Kramer, M., Bintz, L.J. and Tappenden, T.A., Light Duty Fleet Experience with LP Gas Engine Fuels, ASTM STP 525, American Society for Testing and Materials, 1973.

The U S Bureau of Mines has conducted experiments to determine emissions from three vehicles driven through a simulated city driving cycle[1]. The vehicles were chosen to represent six cylinder engines in light delivery service, medium sized eight cylinder high production engines, and medium sized engines common in general utility service.

They were tested on a chassis dynamometer and were operated through the Seven Mode Federal Test Cycle (USA) from a cold start using each of the fuels, petrol, LPG and natural gas. Emission data for all three fuels are included in Table 9 for comparison purposes. The large variations in emission performance of the three engines using the same fuel should be noted.

Two other direct comparisons between petrol and LPG engines are shown in Figure 4 and Table 10. The fact that the data have different units of emission, parts per million and percent in Figure 4, and grams per mile in Table 10, although the two tests were conducted to the same specification, is an indication of the difficulty of comparing the results of published reports. Although the data of Tables 7-10 are taken from two different test cycles, they support the general conclusion common to all reputable tests: the use of LPG produces less emissions than the use of petrol in motor vehicles. However, the data of Table 11 show that the use of LPG or natural gas, in itself, will not necessarily result in emission reductions sufficient to meet 1975 U S Federal Standards.

Comparing Petrol Engines with Diesel Engines

The available comparisons between petrol and diesel engines are not especially reliable as there are virtually no supporting data concerning engine design and performance. Table 12 illustrates these comparisons. The open chamber diesel engine produces far less CO and HC than petrol engines but the generation of NO_x is similar.

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(1) Allsup, J.R. and Fleming, R.D., Emission Characteristics of Propane as Automotive Fuel, Bureau of Mines, U S Department of Interior.

The prechamber diesel engine has a much superior emission performance with reduced NO_x production. The prechamber concept has for many years proved the value of the combustion principles now being redeveloped in the stratified charge engine. Diesel engines, on balance, seem to have more acceptable emission qualities than comparable petrol engines for particular types of service. However, the comparison is complex and is not pursued in this report.

Diesel Engine Conversion

The only information available on converting diesel engines to use gaseous fuel relates to the Daimler-Benz 11-litre natural gas engine derived from the OM403 diesel engine. The tests were conducted in accordance with the 1975 California specifications for diesel engine emission tests.

The results are shown in Figure 5, which compares a production diesel engine, an experimental low emission diesel engine and the natural gas engine. The emissions are compared with California standards to be effective in 1973 and 1975. Note that the units of emission are gm/bhp hr, a more useful figure for comparing vehicles with widely varying performance requirements.

Figure 5 also shows the fuel penalty paid by the two low emission engines when used in suburban bus service. The natural gas engine suffers a 15 percent increase in specific energy consumption when compared to the production diesel engine. The experimental diesel engine pays a 5 percent power output penalty to meet the 1975 California standards.

Diesel Engine Dual-Fuel System

Tests have been carried out on the performance of a diesel dual-fuel conversion kit marketed in Australia. Although the tests were primarily concerned with power development and smoke, exhaust emissions were also measured. The data on smoke and power are shown in Table 13. The conditions of the test were not stated[1].

(1) 'LPG has Message for Diesel Engines', Truck and Bus Transportation, July 1971.

These tests indicate that the dual-fuel system can increase the horsepower of a standard engine by 28 percent and reduce smoke output at the same time. The consumption of LPG, although not given, was compensated, to some extent, by a reduction in distillate consumption of some 22 percent relative to the standard engine.

The wide range of smoke output indicated that proper adjustment of the diesel fuel system is required or the addition of the LPG system can result in increased, rather than reduced smoke.

RELATIONSHIP BETWEEN EMISSIONS AND PERFORMANCE

The principal exhaust gas pollutants, CO, HC and NO_x, are formed during a complex chain of reactions within the combustion chamber and in the exhaust manifold. The principles employed to reduce these pollutants are the same whether the fuel is distillate, petrol or LPG.

CO and HC are the results of incomplete combustion which is caused by rich fuel-air mixtures and reaction quenching at the cooler combustion chamber walls. NO_x is produced as a result of high flame temperatures followed by rapid cooling during gas expansion. The production of NO_x is related to the combustion temperatures, the compression ratio and the ratio of cylinder surface area to cylinder volume. The particular adjustment of air-fuel ratio and ignition timing has a strong effect on the total and relative amounts of pollutants. A lean fuel-air ratio will reduce the proportion of CO and HC but will increase the flame temperature and the production of NO_x. At extremely lean mixture ratios the amount of all pollutants will be reduced but engines will suffer a very considerable power loss; in addition, petrol engines will suffer from misfire and hard starting.

LPG can be mixed with air in a very lean air-fuel ratio because the gaseous fuel is uniformly mixed with the intake air and because the vapourization and recondensation problems encountered with petrol do not occur. With gaseous fuels the air-fuel ratio will be maintained throughout the induction system and the combustion chamber. These emission advantages are especially important during cold starting and initial running, during which time petrol engines require extremely rich mixtures for satisfactory combustion.

A second property of LPG is also important: the octane rating of propane mixtures is considerably higher than for premium grade petrol. Using LPG it is possible to use higher compression ratios, which provide higher power per unit of displacement and higher thermal efficiency.

Both the gaseous nature and octane rating of LPG indicate that engines designed to operate on LPG with minimum pollutant generation should have a larger displacement and a higher compression ratio than a petrol engine of the same power. Such engines have higher torque at low engine speeds. The extra area under the torque-speed curve permits better utilization of the given gear ratios and consequently better low speed acceleration.

Petrol engines converted to the use of LPG can be tuned to maintain very nearly the same effective power as with petrol, but this can be done only by incurring the penalty of increased exhaust emission. They can be tuned for one of the following: maximum power, minimum fuel consumption, or minimum exhaust emission. The air-fuel ratio and ignition timing must be adjusted differently to obtain any one of these mutually exclusive objectives.

The influence of the air-fuel ratio and ignition timing is best shown diagrammatically. Figure 6 presents the effect of these two variables on engine economy. Figure 7 presents the effect on engine power. Minimum economy and maximum power are obtained by different timing within the range of 30° and 40° BTC. Minimum fuel consumption is obtained when the air-fuel ratio is 17:1 and maximum power occurs over a range of air-fuel ratios as engine speed changes. For the engine tested the optimum air-fuel ratio ranged from 14:1 to 17:1.

The effect of these two variables on exhaust gas emission is shown in Figures 8 and 9. An air-fuel ratio of 17:1 and an ignition timing of 35° BTC, although resulting in nearly maximum fuel economy, does not result in minimum pollutant production. At an air-fuel ratio of 17:1 the generation of HC is very nearly minimised, but the production of NO_x is a maximum.

The trade-offs between power, economy and emissions are best seen by examination of Figure 10 which summarises the results of a vehicle test conducted in accordance with the Seven-Mode U S Federal Test Cycle. With standard ignition timing and an air-fuel ratio in the range of 18.5 to 19.5, the total pollutants are minimised at the expense of slightly increased fuel consumption and a 50 percent reduction in acceleration.

As a practical matter it is improbable that commercial operators would tune for minimum emission in view of the significant loss of power and the reduced economy associated with this objective. The same may well be true for car owners generally. However, even with tuning for maximum power, emission characteristics would be somewhat better than for petrol engines.

IMPLICATIONS OF A LARGE SCALE CONVERSION TO LPG

Aside from the micro-economics of using LPG as a motor vehicle fuel, it is worth reflecting on some of the wider economic implications of a large-scale conversion to LPG usage.

The consumption of motor spirit in Australia during 1972-73 was some 72.4 million barrels, equivalent to 18 times the output of LPG from Australian refineries, and 5 times total extraction, when exports of LPG are included(1). It is obvious

(1) Fuels Branch, Department of Minerals and Energy, Australian Petroleum Statistics, 1972-73.

that, based on Australian resources, LPG cannot immediately replace motor spirit entirely as an automotive power source. The current level of extraction indicates an upper limit within which present domestic demand and potential motor vehicle demand would have to be met.

The quantity of LPG exported in 1972-73 would have been sufficient to power 14 percent of the Australian vehicle fleet in 1972. The corresponding volume of motor spirit replaced would have been double the 1972-73 import level. It would represent 9 percent of the estimated 1979-80 motor spirit requirements for Australia[1].

As a basis for calculation, it was assumed that LPG would replace part of the motor spirit market in capital cities, where the community benefits of reduced air pollution would be most important. A market penetration was assumed on the basis of the conversion of 10 percent of motor vehicles presently recorded as garaged within 15 miles of their registration address, in each capital. The distribution, based on 1971 figures, is shown in Table 14. In total the vehicles represent 5 percent of Australian motor vehicle registrations.

Table 15 shows the quantity of LPG which would be used by the converted vehicles. Due to the large numbers of passenger cars, Category A vehicles would have by far the highest consumption of fuel. Trucks with carrying capacity of over 4 tons, with their higher than average rates of fuel consumption and of distance travelled, would have a higher annual fuel consumption than trucks with under 4 tons carrying capacity.

The LPG consumption for Category A vehicles alone would be almost equal to the 1972-73 level of refinery production. The

(1) Fuels Branch, Department of Minerals and Energy, Forecast Consumption of Primary Fuels, 1972-73 to 1984-85.

total demand for the three categories would be 92 percent of all LPG consumption in 1972-73.

At present, major facilities for LPG storage are located only in Melbourne and Adelaide, although plans are understood to be in hand for the provision of such facilities in Sydney. The assumed automotive demand would require a large scale increase in existing bulk storage facilities, together with major new facilities in Perth and Brisbane, at least.

As well as extending major storage facilities, there would need to be a doubling of the land and sea transport of LPG. Land transport would serve particular bulk movement by road and rail from centres of production, as well as the transport of LPG within each city to supply retail outlets. Sea transport would continue to be used for large scale interstate movement.

With the average number of vehicles per reseller outlet being 285 as at 30 June, 1972, over 900 reseller stations would be needed to sell the fuel to consumers. This is equivalent to 5 percent of Australian reseller sites[(1)]. However, some economies due to outlet rationalization could be expected in a large scale replacement program. This would not be true for the many government and other transport agencies which are already bulk fuel users. They could be expected to become bulk users of LPG, with corresponding additional costs for conversion of their bulk storage facilities.

A further implication of the introduction of LPG into the motor vehicle fleet would be the supply and installation of conversion equipment. At current price levels, providing such equipment on a changeover basis for the 10 percent of vehicles garaged in capital cities would cost some $106 million.

(1) Petroleum Information Bureau, Oil and Australia, 1972.

In general, the costs of conversion and re-structuring of the distribution system would be minimised if an expansion of LPG sales were in step with the growth of the total motor vehicle population.

There are other considerations which relate to a significant level of conversion to LPG usage. For example, reseller sites would be necessary at least along major inter-city roads, dual mode engines would be necessary for vehicles which were expected to travel far from LPG outlets, and a substantial retraining of maintenance personnel in new repair and overhaul procedures would be necessary. While much of the conversion equipment is at present imported, the prospect of providing such equipment for a quarter of a million vehicles points to the possibility of Australian designed and manufactured equipment.

CHAPTER 6 CONCLUSION

Estimated Australian reserves of LPG are sufficient for 80 years supply at the present rate of extraction. If used within Australia this would permit a maximum of 14 percent of motor vehicles to be converted to LPG.

The parametric model shows that there is a range of values of the selected parameters over which it would be economic for owners to convert particular classes of vehicles to LPG operation. The break-even point is highly dependent on the fuel cost differential, fuel consumption, annual distance travelled and life of the vehicle.

The calculations suggest that, from the user's point of view, and at present relative prices, a large proportion of vehicles in Melbourne could profitably be converted to LPG. It would be worthwhile for many truck owners in Sydney, but not nearly as advantageous for passenger cars in that city. The merits of LPG, from the private cost point of view, are attributable to its exemption from excise, rather than any intrinsic superiority over other fuels. If it were to become a significant automotive fuel, this particular merit would almost certainly disappear. Distribution costs would also tend to rise. On the other hand, the wholesale price of LPG (before excise) could probably be lowered if all of Australia's production were used within the country.

From the national point of view, the main consideration is the likely effect on pollution in urban areas. Available data show some degree of improvement when certain engines operate on LPG. However, problems of loss of power and reduced fuel economy when operating on LPG make it unlikely that users would have motor engines tuned to minimise pollution.

All motor vehicles, whatever their fuel, will have their emissions controlled by strict regulations to come into force in 1975 (covering hydrocarbons) and 1976 (covering carbon monoxide and oxides of nitrogen). With its sealed fuel tank, the LPG powered vehicle has an advantage at present over petrol powered vehicles from the point of view of hydrocarbon emission. Testing would be helpful in comparing LPG operation with petrol operation under these new regulations.

Despite the fact that the present Australian market for LPG is small and only growing slowly, breakdowns in supply to major users have occurred over the last few years. These supply problems have been caused in part by the considerable expense and consequent limited availability of LPG storage facilities. Unlike motor spirit which can be stored at atmospheric pressure and temperature, LPG usually requires either refrigerated or high pressure storage equipment. This could be a significant deterrent to conversion by existing bulk users of motor fuel.

While LPG can be used in place of motor spirit in internal combustion engines, it has some disadvantages. It produces less power per unit volume of fuel compared with motor spirit although it has greater energy per unit mass. LPG conversion equipment increases passenger vehicle weight by several percent. There is a difference of opinion in the literature on whether overall maintenance costs are reduced with LPG.

The possibility that vehicles may be designed specifically for LPG has not been addressed directly in this report. Although such engines would clearly have better characteristics than petrol engines converted to LPG operation, the current fine balance of favourable circumstances on which expanded LPG usage would rest makes it improbable that special LPG vehicles will become generally available. In any case, the differences in characteristics are unlikely to alter the general conclusions presented in this report.

To sum up, the widespread adoption of LPG for motor vehicles will be conditional on the cost differential with petrol. From an overall social point of view, there is not a strong case for substantial conversion to LPG; it rests mainly on the moderate reduction in air pollution that would result.

SUPPLY PROBLEMS

In 1971 the Senate Standing Committee on Primary and Secondary Industry and Trade examined a petition from the Shoalhaven Shire Council, NSW, into the supply of LPG to the Australian market.(1)

LPG was supplied to the Council gasworks for conversion to gas for supply to consumers, and the Council was concerned with the high cost of shipping relatively small tonnages to Nowra during periods of peak demand and at times of scheduled and unscheduled refinery shut-downs. The Senate Standing Committee came to a number of conclusions regarding the Council petition; those of general relevance to this paper are set out below:

(i) 'Periodic short-term shortages of LPG do occur within States as a result of refinery shut-downs. These shut-downs may be scheduled or unscheduled, and the evidence shows that in New South Wales they do lead at times to serious shortages of supply of LPG. This situation strongly suggests the desirability of close liaison between refinery producers of gas in order to avoid, as far as possible, simultaneous shut-downs.'

(ii) 'It appears that inadequate storage facilities are held by refineries, distributors and consumers, having regard to supply/demand variables. It would seem that retailers/consumers have a particular responsibility to ensure that they maintain sufficient buffer stocks of LPG to tide them over unexpected shortages. Increased retailer/consumer storages could also be expected to reduce the unit cost of gas purchased from distributors.'

(iii) 'Variability of consumption of LPG in some areas is making demands upon the LPG distribution industry such that the gas is being supplied at an uneconomical cost during some

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(1) Senate Standing Committee on Primary and Secondary Industry and Trade, Report on Availability of Liquefied Petroleum Gas, December 1971.

periods. The Committee notes again in this regard the fact that it has been necessary tc import LPG into Sydney from other States during times of severe shortage of supply ex Sydney refineries and that the cost of such imports has been high.'

(iv) 'While the production of refinery LPG balances the Australian consumption of the gas, there appears to be substantial capacity within refineries to produce more LPG should demand warrant it. The Committee recognises that such production will be governed largely by the economic opportunity in producing more LPG .'

The final comment of the Senate Committee, (iv) above, suggests that it will be possible for Australian refineries to produce increased quantities of LPG which would be an addition to oil and gas field reserves.

COST EXPERIENCE WITH LPG CONVERSIONS

City of Unley, South Australia - 1971 [1]

Bedford KGL truck fitted with Evans garbage compactor body; Century LPG conversion equipment installed by Sagasco.

Fuel Tests

Petrol	(2802 miles)	3.72 mpg
LPG	(2861 miles)	3.34 mpg

Costs

Conversion	$300
LPG	20 cents per gallon
Petrol	40 cents per gallon

Miles per year

8,000

Chicago Transit Authority, USA [2]

Total miles by LPG buses - 716 million.
Period of experience - 19 years.
Results of A.D. Little study - 1960:

A.D.L. compared CTA costs for diesel and LPG buses
A.D.L. assumed fuel costs to be:

LPG - 7.5 cents per US gallon
Diesel - 10.5 cents per US gallon

A.D.L. computed annual operating costs as follows:

Assumed Bus Life	Cost - US cents/mile	
	LPG	Diesel
12 years	13.45 - 14.35	16.50
18 years	12.76 - 13.82	15.75

City of Rocky Mountains, South Carolina, USA (Police Department)[3]

Cost per vehicle per year over 10 year life.

	Petrol - fuelled	LPG - fuelled	Difference
Fuel	$256.00	$219.00	$37.00
Oil	7.56	3.78	3.78
Oil filter	13.50	6.75	6.75
Spark plugs	32.48	9.28	23.20
Maintenance	200.00	100.00	100.00
Fuel pilferage (10%)	25.60	-	25.60
	$ 535.14	$338.81	$ 196.33

NRMA Passenger Car Tests[4]

The NRMA tested a 1968 Holden HK automatic equipped with 186 CID engine, commencing April 1970.

Car converted to LPG using Impco equipment; conversion by ATECO Pty Ltd, Sydney NSW.

Test Results:

	LPG	Petrol
Miles driven	14,062	14,062
Fuel consumption, total gallons	1,035	692.6
Cost per gallon; cents	25.25	46.1
Total fuel cost; dollars	258.75	319.29
Fuel cost; cents per mile	1.84	2.27
Oil consumption; pints per 1,000 miles	1.33	1.33
Total cost of oil; dollars	6.27	20.55
Total fuel and oil cost; cents per mile	1.8846	2.4166
Acceleration: 0-50 mph; sec	9.4	9.0
top gear 30-50 mph; sec	9.4	7.0

Oil life, as determined by Ampol tests, would be at least 15,000 miles for LPG-fuelled vehicle.

Weight of equipment for LPG to provide 400 mile range:

regulator, carburettor, etc.		32 lbs
2 tanks		112
fuel		120
	TOTAL	264 lbs

Weight of equipment for petrol to provide 360 mile range:

equipment		20 (estimate)
tanks		30 (estimate)
fuel (16.5 gallons)		129
	TOTAL	179 lbs

Sources :-

(1) Fisher, C.L. , Report on Operating Test with LPG, City of Unley, South Australia

(2) Denny, Luxon, Hall, Handbook Butane - Propane Gases, Fourth Edition, Chilton Company, Los Angeles, 1962

(3) Svoboda, E.J. , Use of LP Gas for the Control of Motor Vehicle Air Pollution , Marvel-Schebler Division of Borg Warner Corporation, USA

(4) 'What to Expect with LPG in Fleet Car Fuel Conversions', Truck and Bus Transportation, August 1972.

PARAMETRIC MODEL

BASIC CONSIDERATIONS

A parametric model, in the form of a computer program, was designed to investigate the level of savings which would accrue to owners of petrol driven motor vehicles converting to LPG operation. It was designed to take account of two different prices for LPG, representing costs to various users in the cities of Melbourne and Sydney. The basic assumptions of the model are:

- the costs of LPG and premium motor spirit will remain constant for the period of calculation;
- there will be sufficient supplies of LPG to permit the vehicle to operate on LPG for the period of calculation; and
- the LPG equipment will remain on the vehicle for the period of calculation.

The model assumes one price for petrol for each category of consumer. As premium (98 octane) spirit comprised 83 per cent of motor spirit sold in 1972-73, the price of this fuel was used in the model(1). The effect on users of standard (89 octane) spirit, or any other price of petrol, could be obtained by running the model at the appropriate price.

Savings calculated by the model are confined to fuel purchased by the vehicle owner, while the only cost considered is that of converting the vehicle to LPG operation. The model does not take into account social costs or benefits relating to effects such as air pollution, nor is the impact of general vehicle running costs included.

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(1) Fuels Branch, Department of Minerals and Energy, Australian Petroleum Statistics, 1972/73.

PARAMETERS USED

The parameters used in the model cover four user and three vehicle categories and are set out in Appendix C1. It was necessary to make a number of assumptions concerning the various parameters; these are discussed below.

Vehicle Type

Vehicles of Category A comprise passenger cars, station wagons and light commercial vehicles, which have similar average petrol consumption. The figures for petrol consumption were taken from Table 14 of the Australian Bureau of Statistics, Survey of Motor Vehicle Usage, 1971. Trucks were separated into carrying capacities under and over 4 tons; also on the basis of petrol consumption (categories B and C respectively). The categories 'Other Truck Types' and 'Motor Cycles' used in the ABS Survey were not considered.

Cost of Conversion to LPG Operation

Price lists for engine and fuel tank conversions were obtained from firms which specialise in this type of work. The costs selected are typical for vehicles in each category.

Fuel Consumption Penalty

Users of vehicles converted to LPG operation report a wide variation in fuel consumption figures as compared to previous petrol consumption (Annex B). Part of this variation is due to the differing physical properties of LPG and petrol. Part of the variation can also be explained bv driver behaviour, vehicle loading, and traffic conditions. In the circumstances, a uniform penalty of 10 per cent was considered the minimum appropriate figure for application to the assumed petrol consumption figures.

Present Fuel Consumption

These figures were based on Table 14 of the Survey of Motor Vehicle Usage, which gives petrol consumption figures for a range of vehicle types. Since the petrol consumption figures for the vehicle types of Category A are similar, the consumption figure for motor cars and station wagons - 23 miles per gallon - was taken as the average for Category A.

Trucks with under 4 tons carrying capacity have an average petrol consumption figure of 14 miles per gallon. A weighted average petrol consumption was calculated for Category C. The average petrol consumption figure for each vehicle class was varied up and down by 50 per cent to cover expected variations in vehicle performance and driver behaviour.

Fuel costs by Owner Category

Fuel costs are based on the relative prices paid for premium grade motor spirit. At one end of the cost scale is the 'General Public'; it was assumed that the average retail price in each of the cities Sydney and Melbourne was appropriate for this category. Premium spirit is supplied to service stations at a 'retail wholesale' price 6 to 7 cents below retail price; large users of petrol can obtain a discount of 4 cents per gallon from the retail wholesale price. The category 'Medium Transport Operator' was defined as those users who can obtain petrol at this discount.

State and Local Governments are required to pay customs and/or excise duty on fuel purchased for motor vehicle use. In view of the considerable number of vehicles operated by these agencies, they were defined as a separate category. The average of State Tender Board Prices for bulk fuel was used for this category of user, in each city.

The Australian Government does not pay customs or excise duty on motor fuel. Therefore the average contract price for bulk fuel in each city was used for this category.

There is a considerable difference between the price of LPG in Melbourne and Sydney. The retail price for LPG in Melbourne is around 21 cents per gallon (4.6 cents per litre). Large commercial users can expect to obtain supplies at about 18 cents per gallon (4.0 cents per litre). It was assumed that State and Local Governments and the Australian Government would be able to obtain supplies of LPG at a discount of 2 cents below this price, i.e. at 16 cents per gallon (3.5 cents per litre). In Sydney it is expected that the retail price for LPG will be 31 cents per gallon (6.8 cents per litre). In the model the difference of 10 cents per gallon between Melbourne and Sydney prices is maintained for each owner class.

Period of Calculation

Studies carried out by the Tariff Board indicate that the expected life of a commercial vehicle with gross vehicle weight (GVW) exceeding 6,000 lb (2,700 kg) is of the order of 17.5 years(1). While figures for the expected life of passenger cars and commercial vehicles with less than 6,000 lb (2,700 kg) GVW are not available, it is expected that they would be considerably less than this figure. It has been assumed that a period of 12 years would be a reasonable estimate. There are no official figures available on the average period for which the first owner of a motor vehicle retains ownership, but after examining vehicle registration statistics it was estimated that this period would be about four years.

The model can use any period of time for calculating the profitability of converting to LPG operation. The maximum period for calculation is of course the expected life of the vehicle. The calculations presented in Annexes D and E use periods of four and eight years, representing approximately one third and two thirds of the expected life of passenger vehicles and light commercial vehicles, and one quarter and one half of the life of heavy commercial vehicles. The position is taken that the first owner will decide whether or not to convert to LPG on the basis of the period that he expects to retain

(1) Tariff Board, Industry Economics Branch, The Demand for Commercial Vehicles, August 1973

the vehicle, that the equipment will have no salvage value, and will not add to the value of the vehicle when he sells it.

Interest Rates

Rates of seven and ten per cent were used in discounting the value of future fuel-cost savings. Together with the periods of four and eight years, the two interest rates permit an assessment of the sensitivity of the calculations to these factors.

COST COMPARISON

The model compares the initial cost of conversion with the discounted stream of cost savings due to the fuel price differential, for a range of specific circumstances of vehicle type, owner category, city of operation, discount rate and period of calculation. The simplifying assumption is made that fuel cost savings accrue only at year ends. No allowance is made for the maintenance cost of LPG equipment on vehicles as it was assessed that overall maintenance costs for petrol and LPG vehicles are comparable. The output of the model is the net present value of conversion under the specified circumstances.

Two sets of calculations are made. Firstly, distances are established for which the present value of savings is either zero or $500 for specified sets of cost variables. For the fuel costs, differences in price between petrol and LPG are taken as positive when the cost of petrol is greater than the cost of LPG per unit volume. These cost differentials are tabulated in steps of 1 cent per litre, as well as for the actual differences between the costs of LPG and petrol which now apply in Sydney and Melbourne.

In the second set of calculations, cost differentials are established for a range of fuel consumption for each vehicle type, using current fuel prices in Sydney and Melbourne and specified annual travel distances.

RESULTS

A portion of the calculations are presented as computer printout in Annexes D and E. Selected results are shown graphically in Figures 2 and 3. The first part of the selected results shows break-even distances, and the second part shows the break-even fuel cost differentials.

PARAMETERS USED IN FUEL COST SAVINGS MODEL

There are three vehicle categories and four owner categories.

Vehicle Category A

Vehicle type: Cars, station wagons and light commercial vehicles

Cost of conversion to LPG operation: $400.00

Fuel consumption penalty: 10%

Present petrol consumption of vehicle type:

4.07 km per litre	(11.5 miles per gallon)
8.14 km per litre	(23.0 miles per gallon)
12.21 km per litre	(34.5 miles per gallon)

Vehicle Category B

Vehicle type: Trucks, rigid and articulated, carrying capacity under 4 tons

Cost of conversion to LPG operation: $450.00

Fuel consumption penalty: 10%

Present petrol Consumption of vehicle type:

2.48 km per litre	(7.0 miles per gallon)
4.96 km per litre	(14.0 miles per gallon)
7.44 km per litre	(21.0 miles per gallon)

Vehicle Category C

Vehicle type: Trucks, rigid and articulated, carrying capacity over 4 tons.

Cost of conversion to LPG operation: $600.00

Fuel consumption penalty: 10%

Present petrol consumption of vehicle type:

1.35 km per litre	(3.8 miles per gallon)
2.70 km per litre	(7.6 miles per gallon)
4.05 km per litre	(11.4 miles per gallon)

Owner Category 1:

- General Public

  Fuel costs:

Petrol:	11.86 cents per litre	(53.9 cents per gallon)
LPG:		
(Sydney)	6.82 cents per litre	(31.0 cents per gallon)
(Melbourne)	4.62 cents per litre	(21.0 cents per gallon)

Owner Category 2:

- Medium Transport Operator

  Fuel costs:

Petrol:	9.37 cents per litre	(42.6 cents per gallon)
LPG:		
(Sydney)	6.16 cents per litre	(28.0 cents per gallon)
(Melbourne)	3.96 cents per litre	(18.0 cents per gallon)

Owner Category 3:

- State and Local Government

  Fuel costs:

Petrol:	8.32 cents per litre	(37.8 cents per gallon)
LPG:		
(Sydney)	5.72 cents per litre	(26.0 cents per gallon)
(Melbourne)	3.52 cents per litre	(16.0 cents per gallon)

Owner Category 4:

- Australian Government

  Fuel costs:

Petrol:	3.45 cents per litre	(15.7 cents per gallon)
LPG:		
(Sydney)	5.72 cents per litre	(26.0 cents per gallon)
(Melbourne)	3.52 cents per litre	(16.0 cents per gallon)

Period for which present value of savings calculated

- 4 years
- 8 years

Discount Rates

- 7%
- 10%

Cost differential between one litre of petrol and one litre of LPG

- Minimum to maximum with up to three steps of 1 cent per litre (4.5 cents/gallon)

ANNEX D

This Annex contains computer calculations of distances required to break even and to earn $500 surplus for vehicles of average fuel consumption. Calculations for Australian Government vehicles have been omitted since fuel cost differentials are negative.

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... GENERAL PUBLIC.
FUEL CONSUMPTION .... 8.14 KM / LITRE
FUEL COSTS:
PETROL .... 11.86 CENTS / LITRE
LPG (SYDNEY) .... 6.82 CENTS / LITRE
LPG (MELBOURNE) ..... 4.62 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	***	***
		2.0	94799	213298
		3.0	45471	102311
		* 5.0	22057	49629
		** 7.2	14182	31910
4	10.0	1.0	***	***
		2.0	101299	227923
		3.0	48589	109326
		* 5.0	23569	53032
		** 7.2	15154	34097
8	7.0	1.0	***	***
		2.0	53774	120993
		3.0	25793	58035
		* 5.0	12512	28152
		** 7.2	8044	18100
8	10.0	1.0	***	***
		2.0	60189	135425
		3.0	28870	64958
		* 5.0	14004	31510
		** 7.2	9004	20260

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)
*** .. AFTER TAKING INTO ACCOUNT FUEL CONSUMPTION PENALTY OF 10%, THE FUEL COST DIFFERENTIAL BECOMES NEGATIVE; DISTANCES ARE NOT CALCULATED IN SUCH CASES.

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
FUEL CONSUMPTION .... 8.14 KM / LITRE
FUEL COSTS:
PETROL .... 9.37 CENTS / LITRE
LPG (SYDNEY) .... 6.16 CENTS / LITRE
LPG (MELBOURNE) ..... 3.96 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	589720	1326870
		2.0	76110	171247
		3.0	40680	91530
		* 3.2	37057	83379
		** 5.4	19171	43136
4	10.0	1.0	630151	1417840
		2.0	81328	182988
		3.0	43469	97805
		* 3.2	39598	89096
		** 5.4	20486	46094
8	7.0	1.0	334517	752664
		2.0	43173	97139
		3.0	23075	51920
		* 3.2	21020	47296
		** 5.4	10875	24469
8	10.0	1.0	374419	842443
		2.0	48323	108726
		3.0	25828	58113
		* 3.2	23528	52938
		** 5.4	12172	27387

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
FUEL CONSUMPTION .... 8.14 KM / LITRE
FUEL COSTS:
PETROL .... 8.32 CENTS / LITRE
LPG (SYDNEY) .... 5.72 CENTS / LITRE
LPG (MELBOURNE) ..... 3.52 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	358677	807024
		2.0	70268	158103
		* 2.6	47399	106649
		3.0	38949	87636
		** 4.8	21611	48625
4	10.0	1.0	383269	862356
		2.0	75086	168943
		* 2.6	50649	113962
		3.0	41619	93644
		** 4.8	23093	51959
8	7.0	1.0	203459	457784
		2.0	39859	89683
		* 2.6	26887	60496
		3.0	22093	49711
		** 4.8	12258	27582
8	10.0	1.0	227728	512388
		2.0	44614	100381
		* 2.6	30094	67713
		3.0	24729	55641
		** 4.8	13721	30872

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... GENERAL PUBLIC.
FUEL CONSUMPTION .... 4.96 KM / LITRE
FUEL COSTS:
    PETROL .... 11.86 CENTS / LITRE
    LPG (SYDNEY) .... 6.82 CENTS / LITRE
    LPG (MELBOURNE) .... 4.62 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY .... 10 %

PERIOD (YRS)	DISC RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	***	***
		2.0	64985	137191
		3.0	31170	65805
		* 5.0	15120	31921
		** 7.2	9721	20524
4	10.0	1.0	***	***
		2.0	69440	146597
		3.0	33308	70317
		* 5.0	16157	34109
		** 7.2	10388	21931
8	7.0	1.0	***	***
		2.0	36862	77821
		3.0	17681	37327
		* 5.0	8577	18107
		** 7.2	5514	11642
8	10.0	1.0	***	***
		2.0	41259	87104
		3.0	19790	41780
		* 5.0	9600	20267
		** 7.2	6172	13031

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)
*** .. AFTER TAKING INTO ACCOUNT FUEL CONSUMPTION PENALTY OF 10%, THE FUEL COST DIFFERENTIAL BECOMES NEGATIVE; DISTANCES ARE NOT CALCULATED IN SUCH CASES.

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
FUEL CONSUMPTION .... 4.96 KM / LITRE
FUEL COSTS:
PETROL .... 9.37 CENTS / LITRE
LPG (SYDNEY) .... 6.16 CENTS / LITRE
LPG (MELBOURNE) ..... 3.96 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	404254	853426
		2.0	52173	110144
		3.0	27886	58871
		* 3.2	25403	53628
		** 5.4	13142	27744
4	10.0	1.0	431973	911943
		2.0	55750	117696
		3.0	29798	62907
		* 3.2	27144	57305
		** 5.4	14043	29647
8	7.0	1.0	229313	484105
		2.0	29595	62479
		3.0	15818	33394
		* 3.2	14409	30420
		** 5.4	7454	15738
8	10.0	1.0	256665	541850
		2.0	33125	69931
		3.0	17705	37377
		* 3.2	16128	34049
		** 5.4	8344	17615

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
FUEL CONSUMPTION .... 4.96 KM / LITRE
FUEL COSTS:
PETROL .... 8.32 CENTS / LITRE
LPG (SYDNEY) .... 5.72 CENTS / LITRE
LPG (MELBOURNE) ..... 3.52 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	245875	519069
		2.0	48169	101690
		* 2.6	32492	68595
		3.0	26699	56366
		** 4.8	14814	31275
4	10.0	1.0	262732	554658
		2.0	51471	108662
		* 2.6	34720	73299
		3.0	28530	60231
		** 4.8	15830	33419
8	7.0	1.0	139472	294441
		2.0	27323	57683
		* 2.6	18431	38910
		3.0	15145	31973
		** 4.8	8403	17740
8	10.0	1.0	156108	329562
		2.0	30583	64564
		* 2.6	20630	43552
		3.0	16952	35787
		** 4.8	9405	19857

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... GENERAL PUBLIC.
FUEL CONSUMPTION .... 2.70 KM / LITRE
FUEL COSTS:
PETROL .... 11.86 CENTS / LITRE
LPG (SYDNEY) .... 6.82 CENTS / LITRE
LPG (MELBOURNE) ..... 4.62 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	***	***
		2.0	47166	86472
		3.0	22624	41477
		* 5.0	10974	20120
		** 7.2	7056	12936
4	10.0	1.0	***	***
		2.0	50400	92401
		3.0	24175	44321
		* 5.0	11727	21499
		** 7.2	7540	13823
8	7.0	1.0	***	***
		2.0	26755	49051
		3.0	12833	23528
		* 5.0	6225	11413
		** 7.2	4002	7338
8	10.0	1.0	***	***
		2.0	29946	54902
		3.0	14364	26334
		* 5.0	6967	12774
		** 7.2	4480	8213

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)
*** .. AFTER TAKING INTO ACCOUNT FUEL CONSUMPTION PENALTY OF 10%, THE FUEL COST DIFFERENTIAL BECOMES NEGATIVE; DISTANCES ARE NOT CALCULATED IN SUCH CASES.

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
FUEL CONSUMPTION .... 2.70 KM / LITRE
FUEL COSTS:
PETROL .... 9.37 CENTS / LITRE
LPG (SYDNEY) .... 6.16 CENTS / LITRE
LPG (MELBOURNE) ..... 3.96 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	293411	537920
		2.0	37868	69424
		3.0	20240	37106
		* 3.2	18437	33802
		** 5.4	9538	17487
4	10.0	1.0	313528	574802
		2.0	40464	74184
		3.0	21627	39651
		* 3.2	19701	36120
		** 5.4	10192	18686
8	7.0	1.0	166437	305134
		2.0	21480	39381
		3.0	11481	21048
		* 3.2	10458	19174
		** 5.4	5410	9919
8	10.0	1.0	186289	341531
		2.0	24042	44078
		3.0	12850	23559
		* 3.2	11706	21461
		** 5.4	6056	11103

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNUAL DISTANCES REQUIRED TO BREAK EVEN AND TO EARN $500 SURPLUS.

VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
FUEL CONSUMPTION .... 2.70 KM / LITRE
FUEL COSTS:
    PETROL .... 8.32 CENTS / LITRE
    LPG (SYDNEY) .... 5.72 CENTS / LITRE
    LPG (MELBOURNE) ..... 3.52 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PERIOD (YRS)	DISCT RATE (%)	COST DIFFTL (CENTS/ LITRE)	ANNUAL DISTANCE TO BREAK EVEN (KM.)	ANNUAL DISTANCE FOR $500 SURPLUS (KM.)
4	7.0	1.0	178457	327172
		2.0	34961	64096
		* 2.6	23583	43236
		3.0	19379	35528
		** 4.8	10752	19713
4	10.0	1.0	190693	349604
		2.0	37358	68490
		* 2.6	25200	46200
		3.0	20707	37964
		** 4.8	11489	21064
8	7.0	1.0	101229	185588
		2.0	19831	36358
		* 2.6	13377	24525
		3.0	10992	20153
		** 4.8	6099	11182
8	10.0	1.0	113304	207725
		2.0	22197	40695
		* 2.6	14973	27451
		3.0	12303	22557
		** 4.8	6826	12516

NOTE: * .. FUEL PRICE DIFFERENTIAL (SYDNEY)
** .. FUEL PRICE DIFFERENTIAL (MELBOURNE)

10 KM / LITRE = 28.2 MPG
10 MPG = 3.54 KM/LITRE

ANNEX E

This Annex contains computer calculations of fuel cost differentials required to break even for a range of fuel consumption.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... GENERAL PUBLIC.
PREMIUM SPIRIT COSTS .... 11.86 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY .... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
4.07	10000	5.45	4	7.0
	10000	5.75	4	10.0
	10000	3.56	8	7.0
	10000	3.85	8	10.0
	40000	2.17	4	7.0
	40000	2.25	4	10.0
	40000	1.70	8	7.0
	40000	1.77	8	10.0
	70000	1.70	4	7.0
	70000	1.75	4	10.0
	70000	1.43	8	7.0
	70000	1.47	8	10.0
8.14	10000	9.82	4	7.0
	10000	10.42	4	10.0
	10000	6.04	8	7.0
	10000	6.63	8	10.0
	40000	3.26	4	7.0
	40000	3.41	4	10.0
	40000	2.32	8	7.0
	40000	2.47	8	10.0
	70000	2.33	4	7.0
	70000	2.41	4	10.0
	70000	1.79	8	7.0
	70000	1.87	8	10.0
12.21	10000	**	4	7.0
	10000	**	4	10.0
	10000	8.51	8	7.0
	10000	9.40	8	10.0
	40000	4.36	4	7.0
	40000	4.58	4	10.0
	40000	2.94	8	7.0
	40000	3.16	8	10.0
	70000	2.95	4	7.0
	70000	3.08	4	10.0
	70000	2.14	8	7.0
	70000	2.27	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
PREMIUM SPIRIT COSTS ...... 9.37 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
4.07	10000	5.22	4	7.0
	10000	5.52	4	10.0
	10000	3.33	8	7.0
	10000	3.63	8	10.0
	40000	1.94	4	7.0
	40000	2.02	4	10.0
	40000	1.47	8	7.0
	40000	1.55	8	10.0
	70000	1.48	4	7.0
	70000	1.52	4	10.0
	70000	1.21	8	7.0
	70000	1.25	8	10.0
8.14	10000	**	4	7.0
	10000	**	4	10.0
	10000	5.81	8	7.0
	10000	6.40	8	10.0
	40000	3.04	4	7.0
	40000	3.19	4	10.0
	40000	2.09	8	7.0
	40000	2.24	8	10.0
	70000	2.10	4	7.0
	70000	2.19	4	10.0
	70000	1.56	8	7.0
	70000	1.64	8	10.0
12.21	10000	**	4	7.0
	10000	**	4	10.0
	10000	8.29	8	7.0
	10000	9.17	8	10.0
	40000	4.13	4	7.0
	40000	4.35	4	10.0
	40000	2.71	8	7.0
	40000	2.93	8	10.0
	70000	2.72	4	7.0
	70000	2.85	4	10.0
	70000	1.91	8	7.0
	70000	2.04	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
PREMIUM SPIRIT COSTS ...... 8.32 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
4.07	10000	5.13	4	7.0
	10000	5.43	4	10.0
	10000	3.23	8	7.0
	10000	3.53	8	10.0
	40000	1.85	4	7.0
	40000	1.92	4	10.0
	40000	1.38	8	7.0
	40000	1.45	8	10.0
	70000	1.38	4	7.0
	70000	1.42	4	10.0
	70000	1.11	8	7.0
	70000	1.15	8	10.0
8.14	10000	**	4	7.0
	10000	**	4	10.0
	10000	5.71	8	7.0
	10000	6.30	8	10.0
	40000	2.94	4	7.0
	40000	3.09	4	10.0
	40000	2.00	8	7.0
	40000	2.14	8	10.0
	70000	2.00	4	7.0
	70000	2.09	4	10.0
	70000	1.46	8	7.0
	70000	1.55	8	10.0
12.21	10000	**	4	7.0
	10000	**	4	10.0
	10000	8.19	8	7.0
	10000	**	8	10.0
	40000	4.03	4	7.0
	40000	4.26	4	10.0
	40000	2.62	8	7.0
	40000	2.84	8	10.0
	70000	2.63	4	7.0
	70000	2.76	4	10.0
	70000	1.82	8	7.0
	70000	1.95	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... CARS, STATION WAGONS, ETC.
OWNER CATEGORY .... AUSTRALIAN GOVERNMENT LESS EXCISE.
PREMIUM SPIRIT COSTS ...... 3.45 CENTS / LITRE
CONVERSION TO LPG $400
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFIL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
4.07	10000	**	4	7.0
	10000	**	4	10.0
	10000	2.79	8	7.0
	10000	3.09	8	10.0
	40000	1.41	4	7.0
	40000	1.48	4	10.0
	40000	0.93	8	7.0
	40000	1.01	8	10.0
	70000	0.94	4	7.0
	70000	0.98	4	10.0
	70000	0.67	8	7.0
	70000	0.71	8	10.0
8.14	10000	**	4	7.0
	10000	**	4	10.0
	10000	**	8	7.0
	10000	**	8	10.0
	40000	2.50	4	7.0
	40000	2.65	4	10.0
	40000	1.55	8	7.0
	40000	1.70	8	10.0
	70000	1.56	4	7.0
	70000	1.65	4	10.0
	70000	1.02	8	7.0
	70000	1.11	8	10.0
12.21	10000	**	4	7.0
	10000	**	4	10.0
	10000	**	8	7.0
	10000	**	8	10.0
	40000	**	4	7.0
	40000	**	4	10.0
	40000	2.17	8	7.0
	40000	2.39	8	10.0
	70000	2.19	4	7.0
	70000	2.31	4	10.0
	70000	1.38	8	7.0
	70000	1.50	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... GENERAL PUBLIC.
PREMIUM SPIRIT COSTS ...... 11.86 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
2.48	10000	4.07	4	7.0
	10000	4.28	4	10.0
	10000	2.78	8	7.0
	10000	2.98	8	10.0
	40000	1.83	4	7.0
	40000	1.88	4	10.0
	40000	1.50	8	7.0
	40000	1.55	8	10.0
	70000	1.51	4	7.0
	70000	1.54	4	10.0
	70000	1.32	8	7.0
	70000	1.35	8	10.0
4.96	10000	7.07	4	7.0
	10000	7.48	4	10.0
	10000	4.48	8	7.0
	10000	4.88	8	10.0
	40000	2.58	4	7.0
	40000	2.68	4	10.0
	40000	1.93	8	7.0
	40000	2.03	8	10.0
	70000	1.93	4	7.0
	70000	1.99	4	10.0
	70000	1.56	8	7.0
	70000	1.62	8	10.0
7.44	10000	10.06	4	7.0
	10000	10.68	4	10.0
	10000	6.18	8	7.0
	10000	6.78	8	10.0
	40000	3.32	4	7.0
	40000	3.48	4	10.0
	40000	2.35	8	7.0
	40000	2.50	8	10.0
	70000	2.36	4	7.0
	70000	2.45	4	10.0
	70000	1.81	8	7.0
	70000	1.89	8	10.0

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
PREMIUM SPIRIT COSTS ...... 9.37 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFF'L. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISC'T. RATE (%)
2.48	10000	3.85	4	7.0
	10000	4.05	4	10.0
	10000	2.55	8	7.0
	10000	2.75	8	10.0
	40000	1.60	4	7.0
	40000	1.65	4	10.0
	40000	1.28	8	7.0
	40000	1.33	8	10.0
	70000	1.28	4	7.0
	70000	1.31	4	10.0
	70000	1.09	8	7.0
	70000	1.12	8	10.0
4.96	10000	6.84	4	7.0
	10000	7.25	4	10.0
	10000	4.25	8	7.0
	10000	4.66	8	10.0
	40000	2.35	4	7.0
	40000	2.45	4	10.0
	40000	1.70	8	7.0
	40000	1.80	8	10.0
	70000	1.71	4	7.0
	70000	1.77	4	10.0
	70000	1.34	8	7.0
	70000	1.40	8	10.0
7.44	10000	**	4	7.0
	10000	**	4	10.0
	10000	5.95	8	7.0
	10000	6.56	8	10.0
	40000	3.10	4	7.0
	40000	3.25	4	10.0
	40000	2.13	8	7.0
	40000	2.28	8	10.0
	70000	2.14	4	7.0
	70000	2.22	4	10.0
	70000	1.58	8	7.0
	70000	1.67	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
PREMIUM SPIRIT COSTS ...... 8.32 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
2.48	10000	3.75	4	7.0
	10000	3.96	4	10.0
	10000	2.46	8	7.0
	10000	2.66	8	10.0
	40000	1.51	4	7.0
	40000	1.56	4	10.0
	40000	1.18	8	7.0
	40000	1.23	8	10.0
	70000	1.18	4	7.0
	70000	1.21	4	10.0
	70000	1.00	8	7.0
	70000	1.03	8	10.0
4.96	10000	6.75	4	7.0
	10000	7.16	4	10.0
	10000	4.15	8	7.0
	10000	4.56	8	10.0
	40000	2.25	4	7.0
	40000	2.36	4	10.0
	40000	1.61	8	7.0
	40000	1.71	8	10.0
	70000	1.61	4	7.0
	70000	1.67	4	10.0
	70000	1.24	8	7.0
	70000	1.30	8	10.0
7.44	10000	**	4	7.0
	10000	**	4	10.0
	10000	5.85	8	7.0
	10000	6.46	8	10.0
	40000	3.00	4	7.0
	40000	3.16	4	10.0
	40000	2.03	8	7.0
	40000	2.18	8	10.0
	70000	2.04	4	7.0
	70000	2.13	4	10.0
	70000	1.48	8	7.0
	70000	1.57	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY UNDER 4 TONS.
OWNER CATEGORY .... AUSTRALIAN GOVERNMENT LESS EXCISE.
PREMIUM SPIRIT COSTS ...... 3.45 CENTS / LITRE
CONVERSION TO LPG $450
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
2.48	10000	3.31	4	7.0
	10000	**	4	10.0
	10000	2.01	8	7.0
	10000	2.22	8	10.0
	40000	1.06	4	7.0
	40000	1.11	4	10.0
	40000	0.74	8	7.0
	40000	0.79	8	10.0
	70000	0.74	4	7.0
	70000	0.77	4	10.0
	70000	0.56	8	7.0
	70000	0.59	8	10.0
4.96	10000	**	4	7.0
	10000	**	4	10.0
	10000	**	8	7.0
	10000	**	8	10.0
	40000	1.81	4	7.0
	40000	1.91	4	10.0
	40000	1.16	8	7.0
	40000	1.26	8	10.0
	70000	1.17	4	7.0
	70000	1.23	4	10.0
	70000	0.80	8	7.0
	70000	0.86	8	10.0
7.44	10000	**	4	7.0
	10000	**	4	10.0
	10000	**	8	7.0
	10000	**	8	10.0
	40000	2.56	4	7.0
	40000	2.71	4	10.0
	40000	1.59	8	7.0
	40000	1.74	8	10.0
	70000	1.60	4	7.0
	70000	1.69	4	10.0
	70000	1.04	8	7.0
	70000	1.13	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... GENERAL PUBLIC.
PREMIUM SPIRIT COSTS ...... 11.86 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
1.35	10000	3.25	4	7.0
	10000	3.40	4	10.0
	10000	2.31	8	7.0
	10000	2.46	8	10.0
	40000	1.62	4	7.0
	40000	1.66	4	10.0
	40000	1.39	8	7.0
	40000	1.42	8	10.0
	70000	1.39	4	7.0
	70000	1.41	4	10.0
	70000	1.25	8	7.0
	70000	1.28	8	10.0
2.70	10000	5.43	4	7.0
	10000	5.72	4	10.0
	10000	3.54	8	7.0
	10000	3.84	8	10.0
	40000	2.17	4	7.0
	40000	2.24	4	10.0
	40000	1.69	8	7.0
	40000	1.77	8	10.0
	70000	1.70	4	7.0
	70000	1.74	4	10.0
	70000	1.43	8	7.0
	70000	1.47	8	10.0
4.05	10000	7.60	4	7.0
	10000	8.05	4	10.0
	10000	4.78	8	7.0
	10000	5.22	8	10.0
	40000	2.71	4	7.0
	40000	2.82	4	10.0
	40000	2.00	8	7.0
	40000	2.11	8	10.0
	70000	2.01	4	7.0
	70000	2.07	4	10.0
	70000	1.61	8	7.0
	70000	1.67	8	10.0

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... MEDIUM TRANSPORT OPERATOR.
PREMIUM SPIRIT COSTS ...... 9.37 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
1.35	10000	3.03	4	7.0
	10000	3.17	4	10.0
	10000	2.09	8	7.0
	10000	2.23	8	10.0
	40000	1.40	4	7.0
	40000	1.43	4	10.0
	40000	1.16	8	7.0
	40000	1.20	8	10.0
	70000	1.16	4	7.0
	70000	1.18	4	10.0
	70000	1.03	8	7.0
	70000	1.05	8	10.0
2.70	10000	5.20	4	7.0
	10000	5.50	4	10.0
	10000	3.32	8	7.0
	10000	3.61	8	10.0
	40000	1.94	4	7.0
	40000	2.01	4	10.0
	40000	1.47	8	7.0
	40000	1.54	8	10.0
	70000	1.47	4	7.0
	70000	1.52	4	10.0
	70000	1.20	8	7.0
	70000	1.25	8	10.0
4.05	10000	7.37	4	7.0
	10000	7.82	4	10.0
	10000	4.55	8	7.0
	10000	4.99	8	10.0
	40000	2.48	4	7.0
	40000	2.59	4	10.0
	40000	1.78	8	7.0
	40000	1.89	8	10.0
	70000	1.78	4	7.0
	70000	1.85	4	10.0
	70000	1.38	8	7.0
	70000	1.44	8	10.0

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... STATE, LOCAL GOVERNMENTS (INCL. EXCISE).
PREMIUM SPIRIT COSTS ...... 8.32 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
1.35	10000	2.93	4	7.0
	10000	3.08	4	10.0
	10000	1.99	8	7.0
	10000	2.14	8	10.0
	40000	1.30	4	7.0
	40000	1.34	4	10.0
	40000	1.06	8	7.0
	40000	1.10	8	10.0
	70000	1.07	4	7.0
	70000	1.09	4	10.0
	70000	0.93	8	7.0
	70000	0.95	8	10.0
2.70	10000	5.10	4	7.0
	10000	5.40	4	10.0
	10000	3.22	8	7.0
	10000	3.52	8	10.0
	40000	1.84	4	7.0
	40000	1.92	4	10.0
	40000	1.37	8	7.0
	40000	1.45	8	10.0
	70000	1.38	4	7.0
	70000	1.42	4	10.0
	70000	1.11	8	7.0
	70000	1.15	8	10.0
4.05	10000	7.28	4	7.0
	10000	7.73	4	10.0
	10000	4.46	8	7.0
	10000	4.90	8	10.0
	40000	2.39	4	7.0
	40000	2.50	4	10.0
	40000	1.68	8	7.0
	40000	1.79	8	10.0
	70000	1.69	4	7.0
	70000	1.75	4	10.0
	70000	1.28	8	7.0
	70000	1.35	8	10.0

COST DIFFERENTIAL REQUIRED TO BREAK EVEN.
VEHICLE TYPE .... TRUCKS, CARRYING CAPACITY OVER 4 TONS.
OWNER CATEGORY .... AUSTRALIAN GOVERNMENT LESS EXCISE.
PREMIUM SPIRIT COSTS ...... 3.45 CENTS / LITRE
CONVERSION TO LPG $600
LPG CONSUMPTION PENALTY ... 10 %

PREM. FUEL CONSUMPTION (KM / LITRE)	ANNUAL DIST. TRAVELLED (KM.)	DIFFTL. TO BREAK EVEN (CENTS/ LITRE)	PERIOD (YRS)	DISCT. RATE (%)
1.35	10000	2.49	4	7.0
	10000	2.64	4	10.0
	10000	1.55	8	7.0
	10000	1.69	8	10.0
	40000	0.86	4	7.0
	40000	0.89	4	10.0
	40000	0.62	8	7.0
	40000	0.66	8	10.0
	70000	0.62	4	7.0
	70000	0.65	4	10.0
	70000	0.49	8	7.0
	70000	0.51	8	10.0
2.70	10000	**	4	7.0
	10000	**	4	10.0
	10000	2.78	8	7.0
	10000	3.07	8	10.0
	40000	1.40	4	7.0
	40000	1.48	4	10.0
	40000	0.93	8	7.0
	40000	1.00	8	10.0
	70000	0.93	4	7.0
	70000	0.98	4	10.0
	70000	0.67	8	7.0
	70000	0.71	8	10.0
4.05	10000	**	4	7.0
	10000	**	4	10.0
	10000	**	8	7.0
	10000	**	8	10.0
	40000	1.94	4	7.0
	40000	2.06	4	10.0
	40000	1.24	8	7.0
	40000	1.35	8	10.0
	70000	1.25	4	7.0
	70000	1.31	4	10.0
	70000	0.84	8	7.0
	70000	0.91	8	10.0

NOTE: ** .. COST DIFFERENTIAL IS GREATER THAN THE COST OF PREMIUM SPIRIT TO THE USER.

TABLE 1 - PROPERTIES OF COMMERCIAL PROPANE

TEMPERATURE-PRESSURE RELATIONSHIP

Temperature (^oC)	Gauge Pressure kPa	Gauge Pressure psi
-42.1	0	0
15.6	640	92.4
37.8	1190	172.0
60.0	2000	290.3
96.8(a)	4340	631.0

COMPARISON WITH PREMIUM MOTOR SPIRIT (b)

Characteristic	Propane	Petrol
Density of liquid (kg/litre)	0.505	0.780
Gross heating value (kilojoules/kg)	50,150	48,960
Gross heating value (kilojoules/litre)	25,480	35,930
Octane rating (approximate)	110-120	98
Ignition temperatures at atmospheric pressure (^oC)	510-576	450

(a) Temperature above which propane cannot be held as a liquid.
(b) 60^0 API.

Source : Denny, Luxon, Hall, Handbook, Butane-Propane Gases, Fourth Edition, Chilton Company, Los Angeles, 1962

TABLE 2 - USES OF LPG: NORTH AMERICA AND EUROPE, 1969

Application	North America (%)	Europe (%)
Domestic use (including commercial)	42.7	58.2
Industrial fuel	5.3	16.5
Gas industry	1.0	14.6
Automotive	8.2	3.7
Chemical industry	41.7	5.6
Agricultural, exports, etc.	1.1	1.4
	100.0	100.0

Source : Modern Petroleum Technology, Applied Science Publishers (UK), 1973, Chapter 13.

TABLE 3 - LIQUEFIED PETROLEUM GAS: REFINERY OUT-TURN, CONSUMPTION AND EXPORTS, AUSTRALIA

('000 barrels)

	1968-69	1969-70	1970-71	1971-72	1972-73	% increase by weight 1972-73 over 1968-69
Refinery out-turn	3,170	3,367	3,538	3,894	3,991	+23.8
Consumption	3,118	3,371	3,592	3,896	4,206	+32.8
Exports	-	-	4,156	7,503	10,518	-

Source : Fuels Branch, Department of Minerals and Energy, *Australian Petroleum Statistics*, 1972-73

TABLE 4 - ESTIMATES OF CURRENT RESERVES OF LPG, OCTOBER 1973

(Million barrels)

Field	Proved plus provable recoverable from		
	Gas reservoirs	Oil reservoirs	Both oil and gas reservoirs
Dampier sub-basin [a] (on the Northwest Shelf)	446	Negligible	446
Offshore Gippsland [a][b]	286	168	454
Cooper [a][b]	96	2	98
Bowen - Surat [b]	4	Negligible	4
Amadeus [a]	121	6	127
Carnarvon [b]	-	1	1
Perth [b]	3	Negligible	3
TOTAL	956	177	1133

(a) Non-producing fields. (b) Producing fields.

Source: Bureau of Mineral Resources, Department of Minerals and Energy, Canberra.

TABLE 5 - COMPARISON OF FUEL ENERGY COSTS, MELBOURNE, OCTOBER 1973

	Motor spirit Standard	Motor spirit Premium	LPG	Automotive distillate
Heating value (kilojoules/litre)	35.93	35.93	25.48	38.57
Nominal wholesale less excise ($/litre)	0.048	0.054	0.040	0.047
Energy cost ($/megajoule)	1.34	1.50	1.57	1.22
Nominal wholesale including excise ($/litre)	0.097	0.103	0.040	0.096
Energy cost ($/megajoule)	2.70	2.87	1.57	2.49
Retail price ($/litre)	0.112	0.119	0.046	0.110
Energy Cost ($/megajoule)	3.12	3.31	1.81	2.85

TABLE 6 - WEIGHT OF VEHICLE MOUNTED LPG FUEL TANKS

Nominal capacity of tank		Average weight
litres	gallons	kilograms
36	8	23
61	13.5	32
91	20	36
182	40	79
364	80	166

TABLE 7 - AVERAGE EXHAUST EMISSIONS FROM VEHICLES POWERED BY PETROL OR BY LPG

(Grams per mile)

Test details	0 miles (a)		9000 miles		21000 miles		33000 miles	
	Petrol	LPG	Petrol	LPG	Petrol	LPG	Petrol	LPG
Hydrocarbons	2.29	1.93	2.48	2.39	1.86	1.44	2.32	1.68
Carbon monoxide	20.63	3.77	24.40	6.67	22.21	8.07	20.56	7.62
Oxides of nitrogen	5.77	3.82	5.13	2.69	4.34	2.81	3.92	2.69
No. of vehicles in above tests	11	16	6	15	5	14	7	15

(a) Zero miles indicates mileage at which vehicle was converted to LPG operation.

NOTE: 'LPG' indicates vehicles powered by LPG, and fitted with either LPG single fuel or dual fuel equipment.

SOURCE: M. Kramer, L.J. Bintz, and T.A. Tappenden, 'Light duty fleet experience with LP gas engine fuels', ASTM STP 525, American Society for Testing and Materials, 1973.

TABLE 8 - AVERAGE EXHAUST EMISSIONS FROM VEHICLES FITTED WITH EITHER LPG OR DUAL FUEL EQUIPMENT

(Grams per mile)

	0 miles(a)		9000 miles		18000 miles		31000 miles	
	LPG only	Dual fuel	LPG only	Dual fuel	LPG only	Dual fuel	LPG only	Dual fuel
Hydrocarbons	2.36	0.98	2.81	1.22	1.65	1.07	1.81	1.41
Carbon monoxide	4.16	2.92	6.32	7.63	7.80	8.55	6.74	9.37
Oxides of nitrogen	3.94	3.57	2.61	2.92	2.86	2.71	2.80	2.49
No. of vehicles in above tests	11	5	11	4	9	5	10	5

(a) Zero miles indicates the mileage of the vehicle at the time of conversion to LPG single fuel or dual fuel operation.

Source : M. Kramer, L.J. Bintz, and T. A. Tappenden, 'Light duty fleet experience with LP Gas engine fuels', ASTM STP 525, American Society for Testing and Materials, 1973.

TABLE 9 - EMISSIONS FROM PETROL, PROPANE AND NATURAL GAS
(7 - mode Federal test cycle driven from cold start)

Vehicle	Emissions, gm/mile		
	Gasoline[a]	LP-Gas (Propane)[b]	Natural Gas
CARBON MONOXIDE			
250-CID Ford	10.7	5.4	1.5
327-CID Chevrolet	39.6	2.9	3.5
345-CID International Harvester ..	18.0	2.7	2.3
HYDROCARBONS			
250-CID Ford	2.7	1.6	1.7
327-CID Chevrolet	5.3	2.0	2.7
345-CID International Harvester ..	4.4	2.7	2.4
NITROGEN OXIDES[c]			
250-CID Ford	9.2	7.1	4.1
327-CID Chevrolet	6.1	2.0	4.1
345-CID International Harvester ..	10.7	2.3	3.7
ALDEHYDES			
250-CID Ford	0.15	0.10	0.11
327-CID Chevrolet	.14	.19	.11
345-CID International Harvester ..	.19	.19	.14
REACTIVITY, ETHYLENE EQUIVALENTS[d]			
250-CID Ford	0.57	0.37	0.16
327-CID Chevrolet	.45	.40	.14
345-CID International Harvester ..	.54	.39	.12

(a) Engines were operated with manufacturers' recommended adjustments.
(b) Engines were optimised for balanced emissions and performance.
(c) Nitrogen Oxides were expressed as NO_2.
(d) Gram ethylene per gram exhaust hydrocarbon emission.

Source: Allsup, J.R. and Fleming, R.D.: 'Emission characteristics of Propane as Automotive Fuel', Report of Investigations 7672, Bureau of Mines, U.S. Department of the Interior.

TABLE 10 - EXHAUST EMISSIONS, PETROL AND PROPANE ENGINES

(Grams/mile)

Emission	Engine		California Standards	
	Petrol	Propane (a)	1974	1975
Hydrocarbons	4.78	.58	1.5	.5
Carbon monoxide	55.03	6.89	23.0	11.0
Nitrogen oxides	4.20	1.15	1.3	.9

(a) Petrol engine converted to LPG by use of 'Century' conversion kit; engine tested in both configurations in accordance with applicable California test specifications.

Source : State Government Administration, Pollution Solutions, Jan.-Feb.1972.

TABLE 11 - RANGE OF EMISSIONS

(Grams/mile)

	HC	CO	NOx
NATURAL GAS ENGINES (a)			
Automobiles	.50	8.60	2.15
Light trucks	1.10	4.94	1.79
Medium trucks	1.63	5.96	2.38
1975 Federal Standards	.23	2.30	1.00
LPG ENGINES (b)			
Range: from	0.8	1.3	1.2
to	1.8	20.5	3.8
1975 Federal Standards	.23	2.3	1.0

(a) Data from General Service Administration report on natural gas.

(b) Data from Impco Division of A.J. Industries (USA); tested by California Air Resources Board.

Source: California Institute of Technology, Transportation Report, 1972.

TABLE 12 - COMPARISON OF DIESEL AND PETROL ENGINES

Test	HC	CO	NO_x
US-CVS TESTS (grams/mile)			
Prechamber diesel	1.2	5.0	2.2
1963 US average petrol	16.8	125	10
CALIFORNIA DRIVING CYCLE TESTS (grams/mile)			
Open chamber diesel	3.5	5	4
1970 petrol	2.2	23	6
GENERALISED COMPARISON			
Open chamber diesel (a)	150-200 ppm	0.2%	2,000-3,000 ppm
Petrol (b)	900 ppm	3.5%	1,500 ppm

(a) Operated over range of loads and speeds; corrected for excess air. (b) Operated through California driving cycle.

Sources: Watson, H.C., 'Controlling Internal Combustion Engine Emissions', Paper 18, SAE 71 National Convention, Australia, October 1971.
Underwood, A.F., 'Requiem for the piston engine?', Paper 21, SAE 71 National Convention, October 1971.
Morse, R.S. et al, The Automobile and Air Pollution, Part II, U.S. Department of Commerce, December 1967.

TABLE 13 - PERFORMANCE OF COMMERCIAL DUAL-FUEL CONVERSION SYSTEM (a)

Test Conditions	Degree of over fuelling (cc/200 shots)	HP/RPM	Smoke Scale/RPM (b)
Standard engine	0	113/2400	5/2000
Overfuelled	+ 2.2	131/2400	7/2000
Dual-Fuel system	0	145/2400	8/2000
Dual-Fuel system underfuelled	- 1.6	145/2400	5/2000
Dual-Fuel system underfuelled	- 2.8	142/2400	2/2000

Exhaust Emission Reduction During Tests

Item	Percent Reduction
CO	48
HC	99
NOx	50
Black Smoke	85
Smell	reduced

(a) Engine converted was 'popular' make of 400 CID 6 cylinder (6.5 litre) engine with 16:1 compression ratio.

(b) Baccarah scale; employs colour comparison chart graduated from 0 to 10; high readings denote dense smoke. Clean Air Act of London limits reading to 5.

Source: 'LPG has message for diesel engines,' Truck and Bus Transportation, July 1971.

TABLE 14 - NUMBER OF MOTOR VEHICLES GARAGED WITHIN 15 MILES OF REGISTRATION ADDRESS IN CAPITAL CITY URBAN AREAS, 30 SEPTEMBER 1971

(Thousands of vehicles)

CATEGORY	SYDNEY	MELBOURNE	ADELAIDE	BRISBANE	PERTH	HOBART	CANBERRA	DARWIN	TOTAL
A. Cars, station wagons and light commercial vehicles (carrying capacity less than 20 cwt)	829.3	735.2	280.7	265.9	256.8	44.7	53.5	11.9	2478.0
	(53%)	(58%)	(64%)	(41%)	(66%)	(31%)	(93%)	(54%)	(55%)
B. Trucks, carrying capacity under 4 tons	35.6	25.5	9.3	8.6	10.1	1.8	1.7	2.1	94.7
	(45%)	(47%)	(45%)	(24%)	(47%)	(26%)	(88%)	(48%)	(42%)
C. Trucks, carrying capacity over 4 tons	17.0	15.6	6.9	6.6	6.4	1.3	0.6	0.7	55.1
	(31%)	(37%)	(31%)	(21%)	(29%)	(19%)	(81%)	(36%)	(30%)
TOTALS:	881.9	776.3	296.9	281.1	273.3	47.8	55.8	14.7	2627.8

Source: A.B.S. Survey of Motor Vehicle Usage, 30 September 1971.

NOTE : Figures in brackets represent proportion of vehicles garaged within 15 miles of registered address in capital city urban areas to total number of vehicles in same category registered within the State or Territory. The estimates of the numbers of vehicles by vehicle type provided by the 1971 Survey of Motor Vehicle Usage are based on data supplied by the owners of the vehicles. These estimates may differ marginally from Statistics of Motor Vehicles on Register derived in the 1971 Motor Vehicle Census. The Table excludes Other Truck Types, Motor Cycles and Buses.

TABLE 15 - ANNUAL QUANTITY OF LPG REQUIRED TO OPERATE 10 PERCENT OF MOTOR VEHICLES GARAGED WITHIN 15 MILES OF REGISTRATION ADDRESS IN CAPITAL CITY URBAN AREAS, 30 OCTOBER 1971

(LPG Consumption Penalty = 10%)

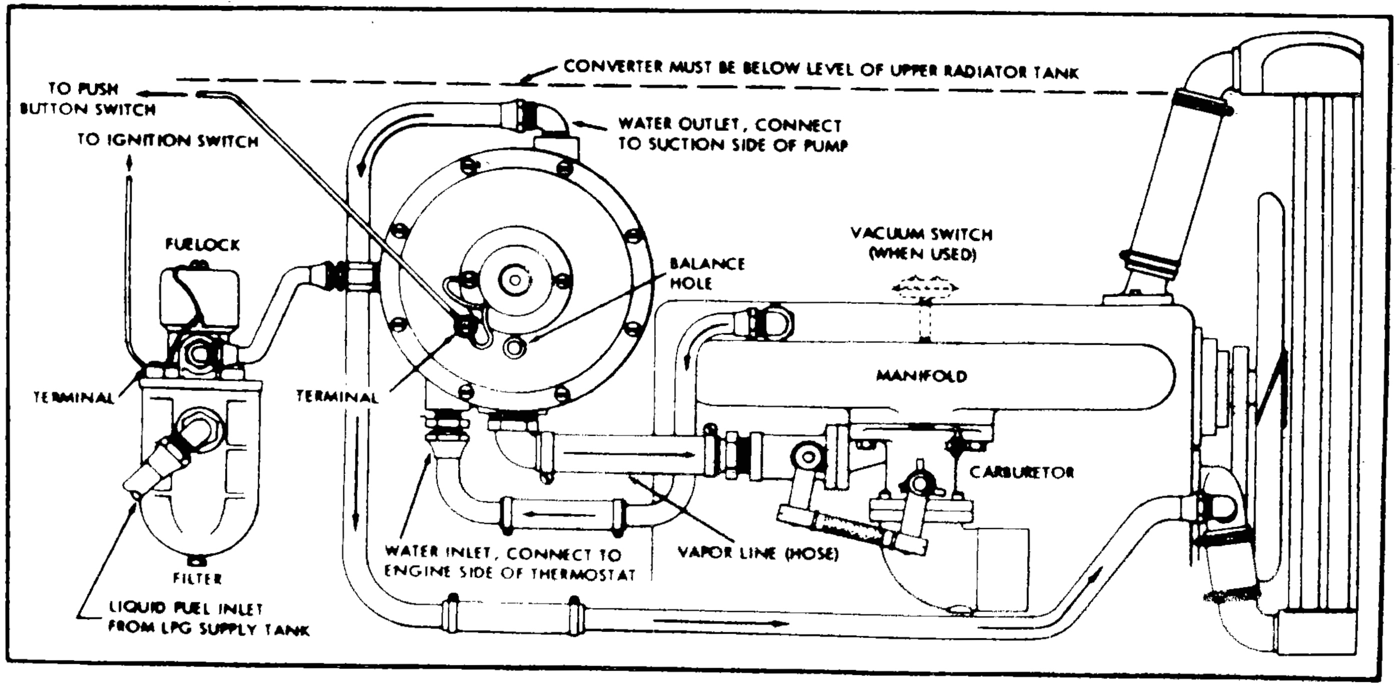
(Thousands of barrels per annum)

CATEGORY	SYDNEY	MELBOURNE	ADELAIDE	BRISBANE	PERTH	HOBART	CANBERRA	DARWIN	TOTAL
A. Cars, station wagons and light commercial vehicles (carrying capacity less than 20 cwt)	1,125.3 (33.4%)	997.6 (29.6%)	380.9 (11.3%)	360.8 (10.7%)	348.5 (10.4%)	60.8 (1.8%)	72.6 (2.2%)	16.1 (0.5%)	3,362.4 (100%)
B. Trucks, carrying capacity under 4 tons	79.1 (37.5%)	56.7 (26.9%)	20.7 (9.8%)	19.1 (9.1%)	22.5 (10.7%)	4.0 (1.9%)	4.0 (1.9%)	4.7 (2.2%)	210.8 (100%)
C. Trucks, carrying capacity over 4 tons	95.6 (30.9%)	87.7 (28.3%)	38.8 (12.5%)	37.1 (12.0%)	36.0 (11.6%)	7.3 (2.4%)	3.4 (1.1%)	3.9 (1.3%)	309.8 (100%)
TOTALS	1,300.0	142.0	440.4	417.0	407.0	71.9	80.0	24.7	3,883.0

NOTE:

Data based on Table 14 of this paper and the A.B.S. Survey of Motor Vehicle Usage, 30 September 1971. It has been assumed that 77 percent of trucks of over 4 tons carrying capacity are petrol powered. This is based on the ratio of petrol to diesel driven trucks registered in Australia during 1972, A.B.S. Motor Vehicle Registrations, 1972.

FIGURE 1



LPG conversion unit for petrol engine.

<u>Source</u>: Brooklands-Machins Pty. Ltd. Victoria.

BREAK EVEN DISTANCE - MELBOURNE

OWNER CATEGORY : GENERAL PUBLIC

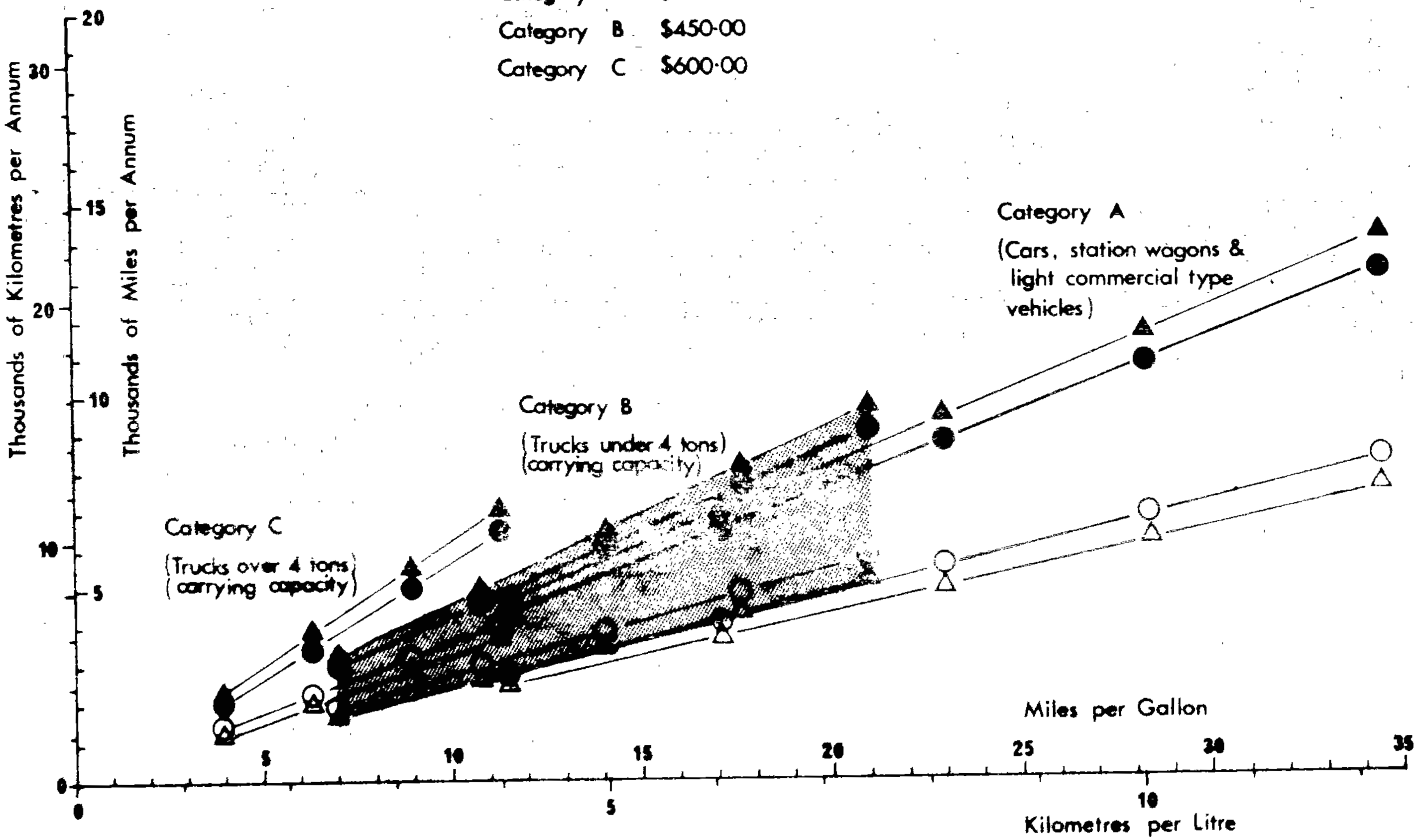
COST OF PETROL : 11·86 cents per litre
: 53·9 cents per gallon

COST OF LPG : 4·62 cents per litre
: 21·0 cents per gallon

COST OF CONVERSION TO L.P.G.

Category A $400·00
Category B $450·00
Category C $600·00

SYMBOL	YEARS	%
▲	4	10
●	4	7
○	8	10
△	8	7

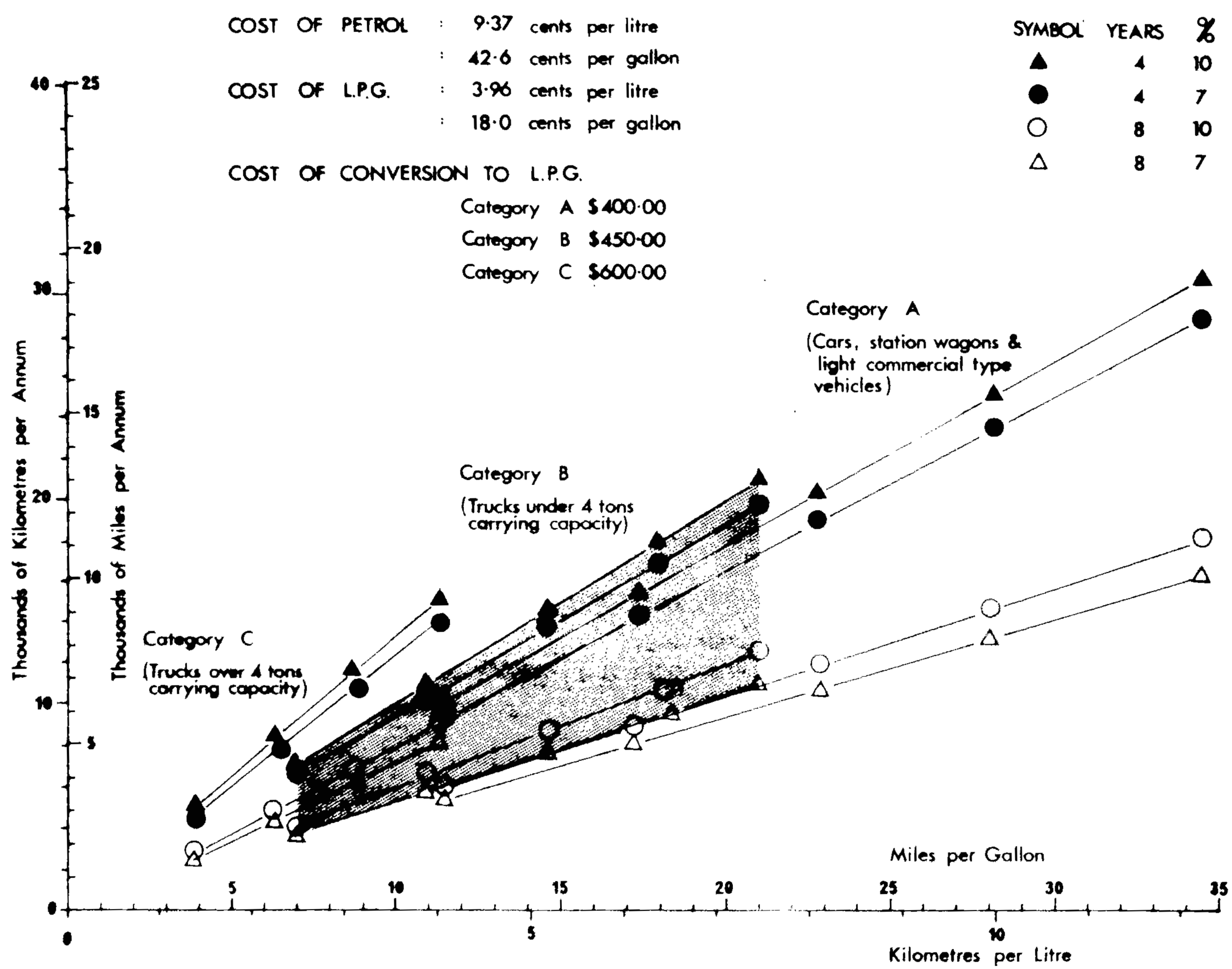


PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2A

BREAK EVEN DISTANCE - MELBOURNE

OWNER CATEGORY : MEDIUM TRANSPORT OPERATOR



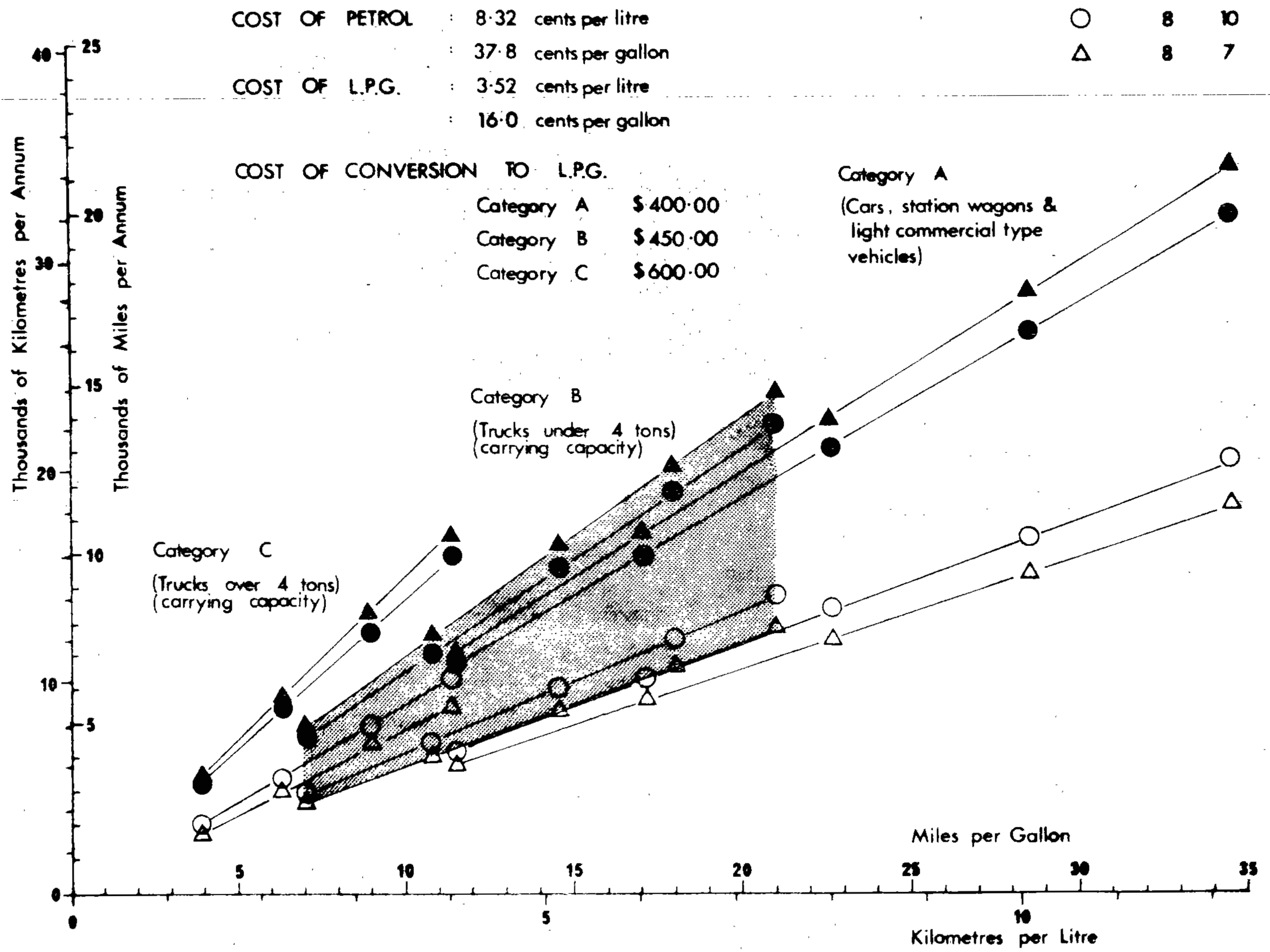
PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2B

BREAK EVEN DISTANCE - MELBOURNE

OWNER CATEGORY : STATE AND LOCAL GOVERNMENTS

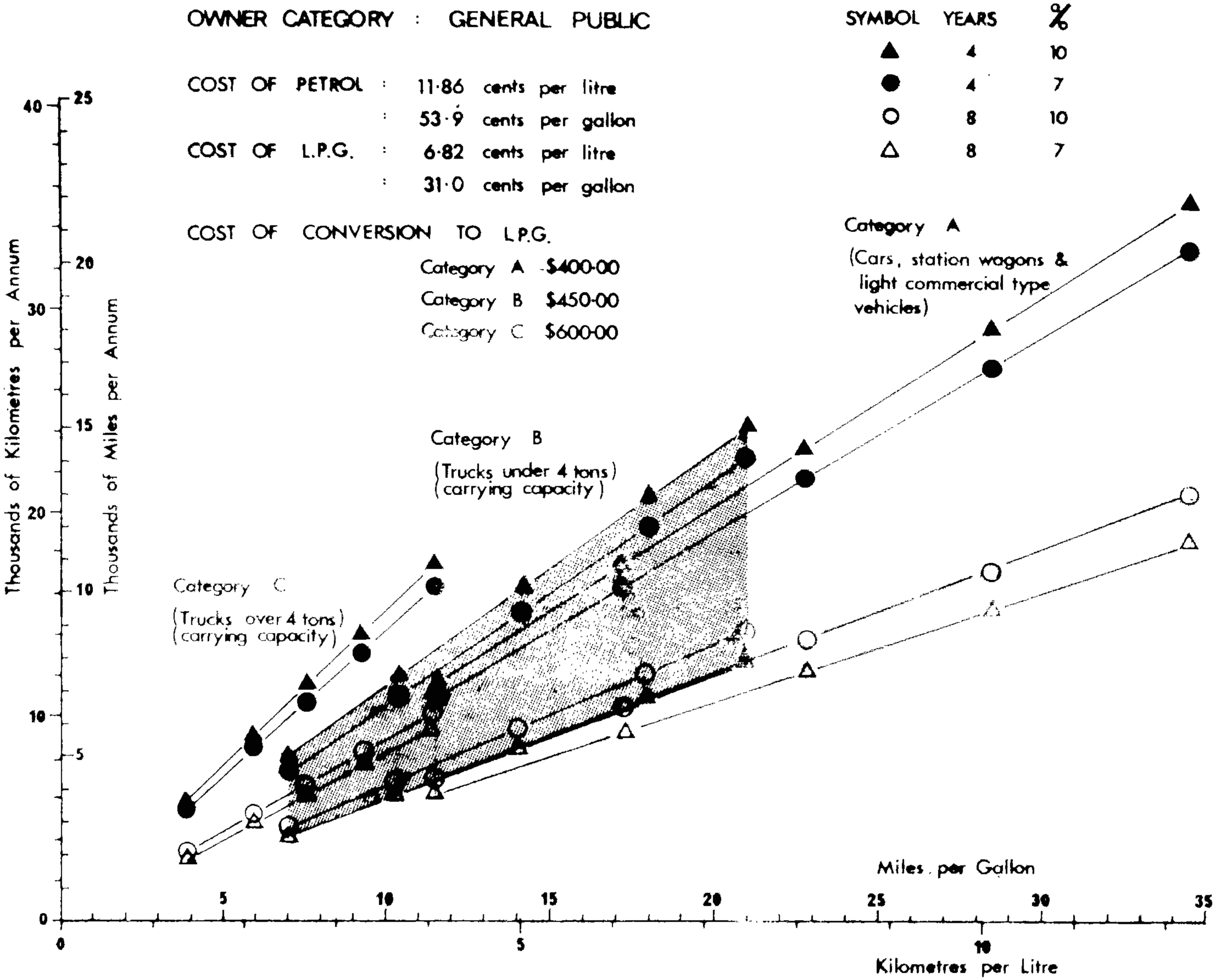
SYMBOL	YEARS	%
▲	4	10
●	4	7
○	8	10
△	8	7



PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2C

BREAK EVEN DISTANCE - SYDNEY



PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2D

BREAK EVEN DISTANCE - SYDNEY

OWNER CATEGORY MEDIUM TRANSPORT OPERATOR

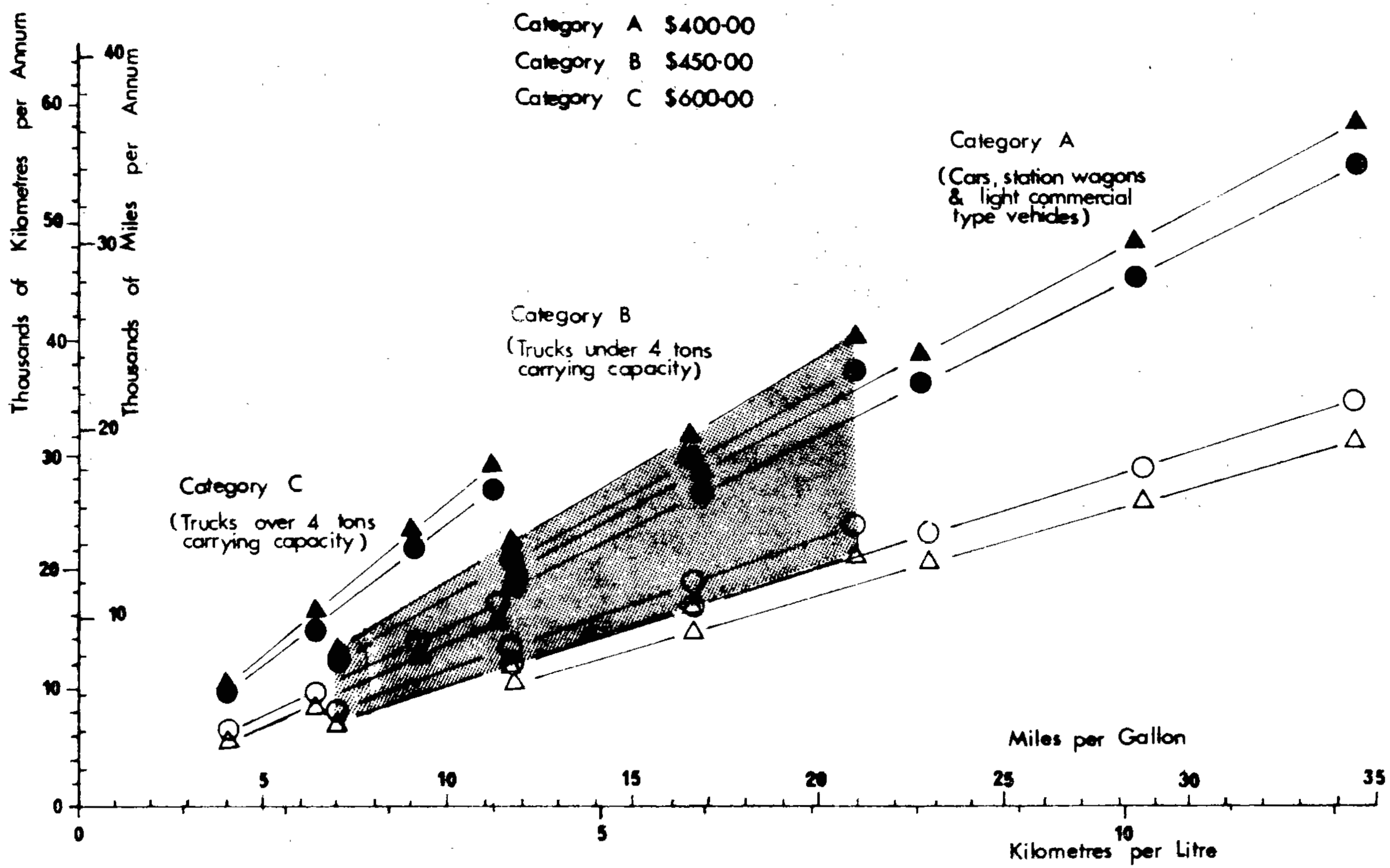
COST OF PETROL : 9·37 cents per litre
: 42·6 cents per gallon

COST OF L.P.G. : 6·16 cents per litre
: 28·0 cents per gallon

SYMBOL	YEARS	%
▲	4	10
●	4	7
○	8	10
△	8	7

COST OF CONVERSION TO L.P.G.

Category A $400·00
Category B $450·00
Category C $600·00



PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2E

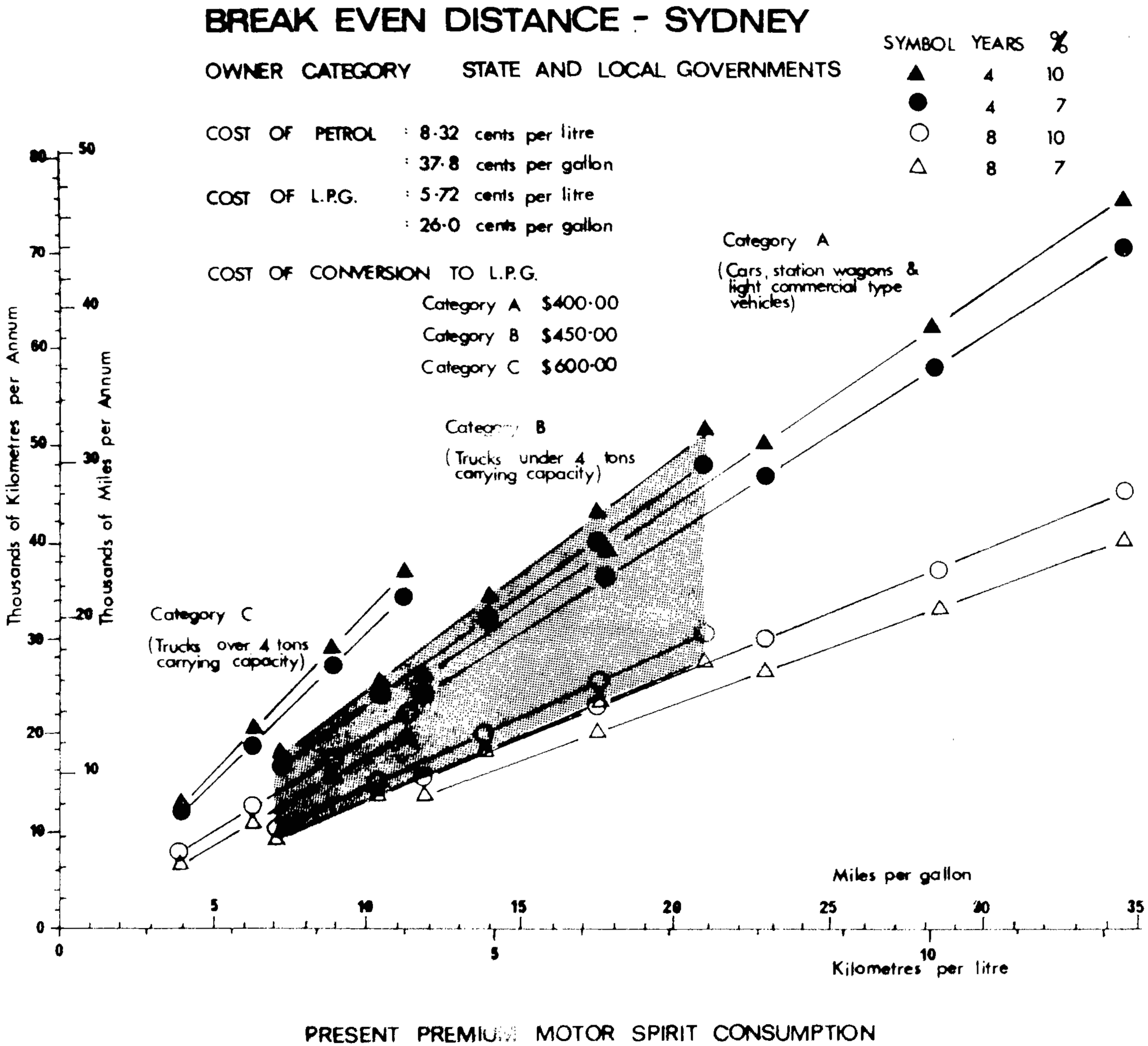

BREAK EVEN DISTANCE - SYDNEY
OWNER CATEGORY STATE AND LOCAL GOVERNMENTS
SYMBOL YEARS %
4 10
4 7
8 10
8 7
COST OF PETROL : 8·32 cents per litre
: 37·8 cents per gallon
COST OF L.P.G. : 5·72 cents per litre
: 26·0 cents per gallon
COST OF CONVERSION TO L.P.G.
Category A $400·00
Category B $450·00
Category C $600·00
Category A
(Cars, station wagons & light commercial type vehicles)
(Trucks under 4 tons carrying capacity)
Category C
(Trucks over 4 tons carrying capacity)
Thousands of Kilometres per Annum
Thousands of Miles per Annum
Miles per gallon
Kilometres per litre
PRESENT PREMIUM MOTOR SPIRIT CONSUMPTION

FIGURE 2F

FIGURE 3 - NOTES

The following three graphs show cost differentials corresponding to various annual distances travelled for State and Local Government vehicles with average motor spirit consumption.

The graphs can be used to read off cost differentials applicable to the other owner categories for the specified average fuel consumption. The following approximate amounts should be added or subtracted from the cost differential obtained from the graphs to obtain the differentials applicable to the other owners.

Owner Category	Amount
General Public	Add 0.3 cent/litre (1.5 cents/gallon)
Medium Transport Operator	Add 0.1 cent/litre (0.5 cent/gallon)
Australian Government	Subtract 0.4 cent/litre (2.0 cents/gallon)

FIGURE 3 A

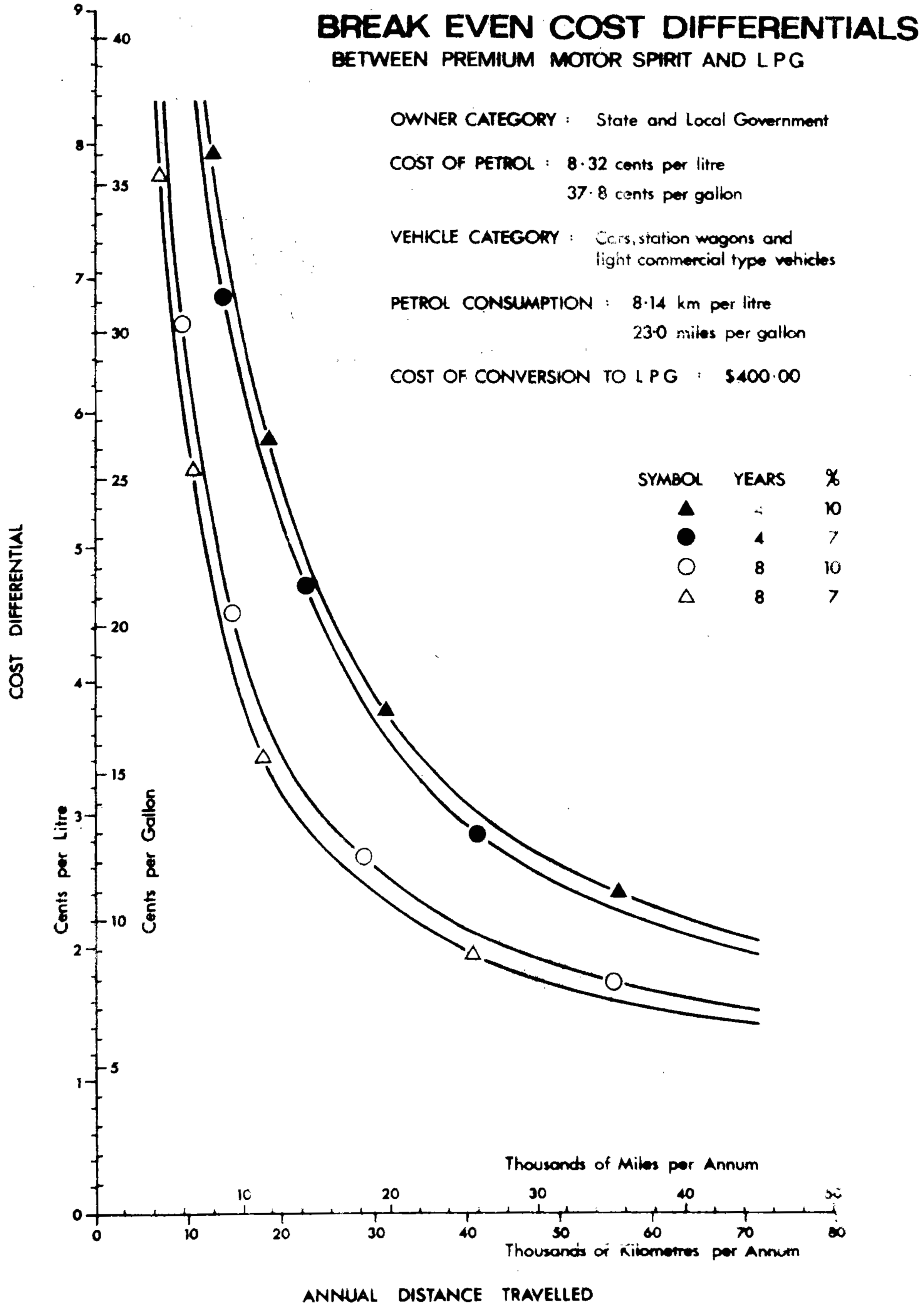

BREAK EVEN COST DIFFERENTIALS
BETWEEN PREMIUM MOTOR SPIRIT AND L P G
OWNER CATEGORY : State and Local Government
COST OF PETROL : 8·32 cents per litre
37·8 cents per gallon
VEHICLE CATEGORY : Cars, station wagons and light commercial type vehicles
PETROL CONSUMPTION : 8·14 km per litre
23·0 miles per gallon
COST OF CONVERSION TO L P G : $400·00
SYMBOL YEARS %
▲ 4 10
● 4 7
○ 8 10
△ 8 7
COST DIFFERENTIAL
Cents per Litre
Cents per Gallon
Thousands of Miles per Annum
Thousands of Kilometres per Annum
ANNUAL DISTANCE TRAVELLED

FIGURE 3 B

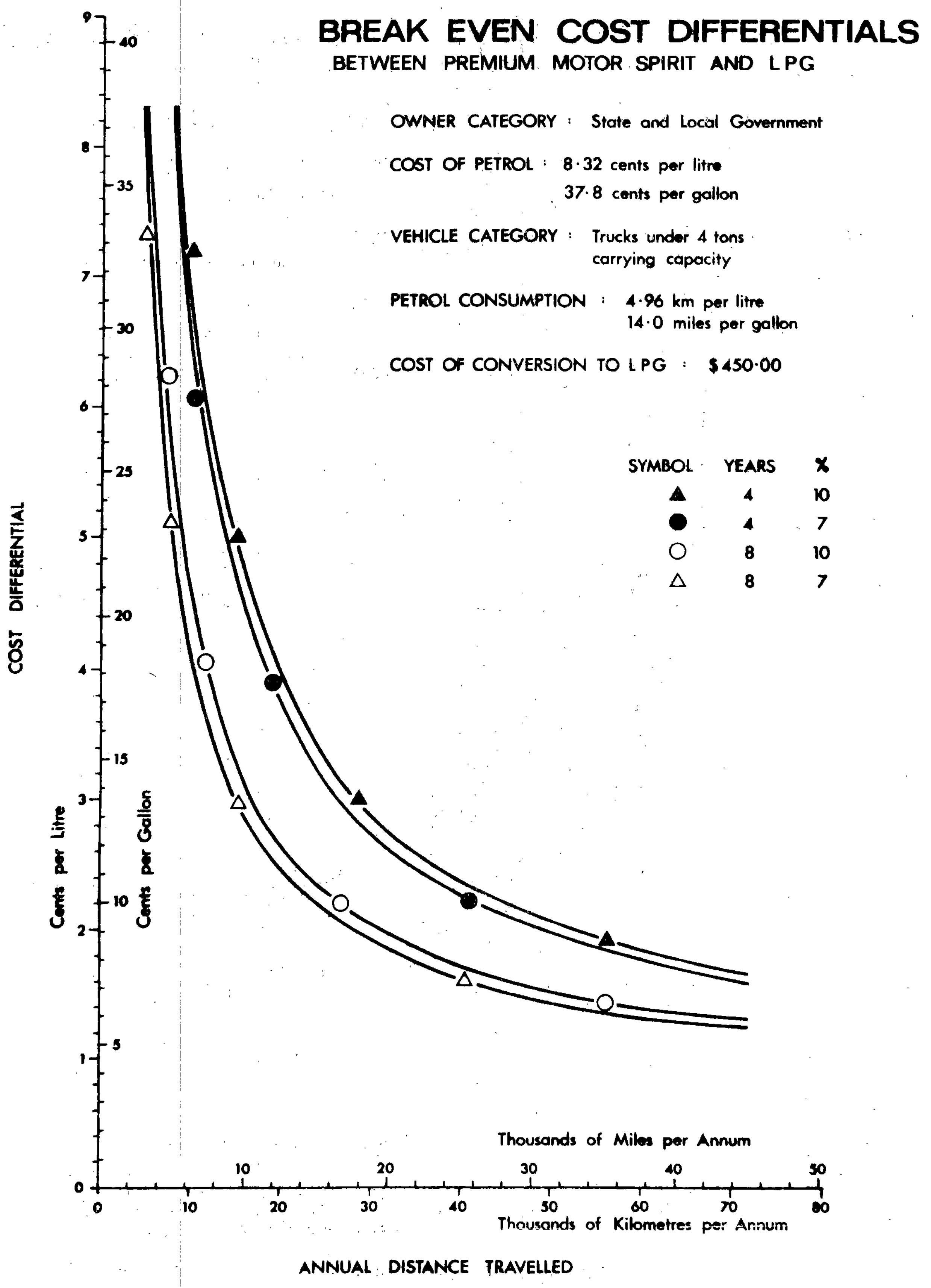

BREAK EVEN COST DIFFERENTIALS
BETWEEN PREMIUM MOTOR SPIRIT AND LPG
OWNER CATEGORY : State and Local Government
COST OF PETROL : 8·32 cents per litre
37·8 cents per gallon
VEHICLE CATEGORY : Trucks under 4 tons carrying capacity
PETROL CONSUMPTION : 4·96 km per litre
14·0 miles per gallon
COST OF CONVERSION TO LPG : $450·00
SYMBOL YEARS %
4 10
4 7
8 10
8 7
COST DIFFERENTIAL
Cents per Litre
Cents per Gallon
Thousands of Miles per Annum
Thousands of Kilometres per Annum
ANNUAL DISTANCE TRAVELLED

FIGURE 3 C

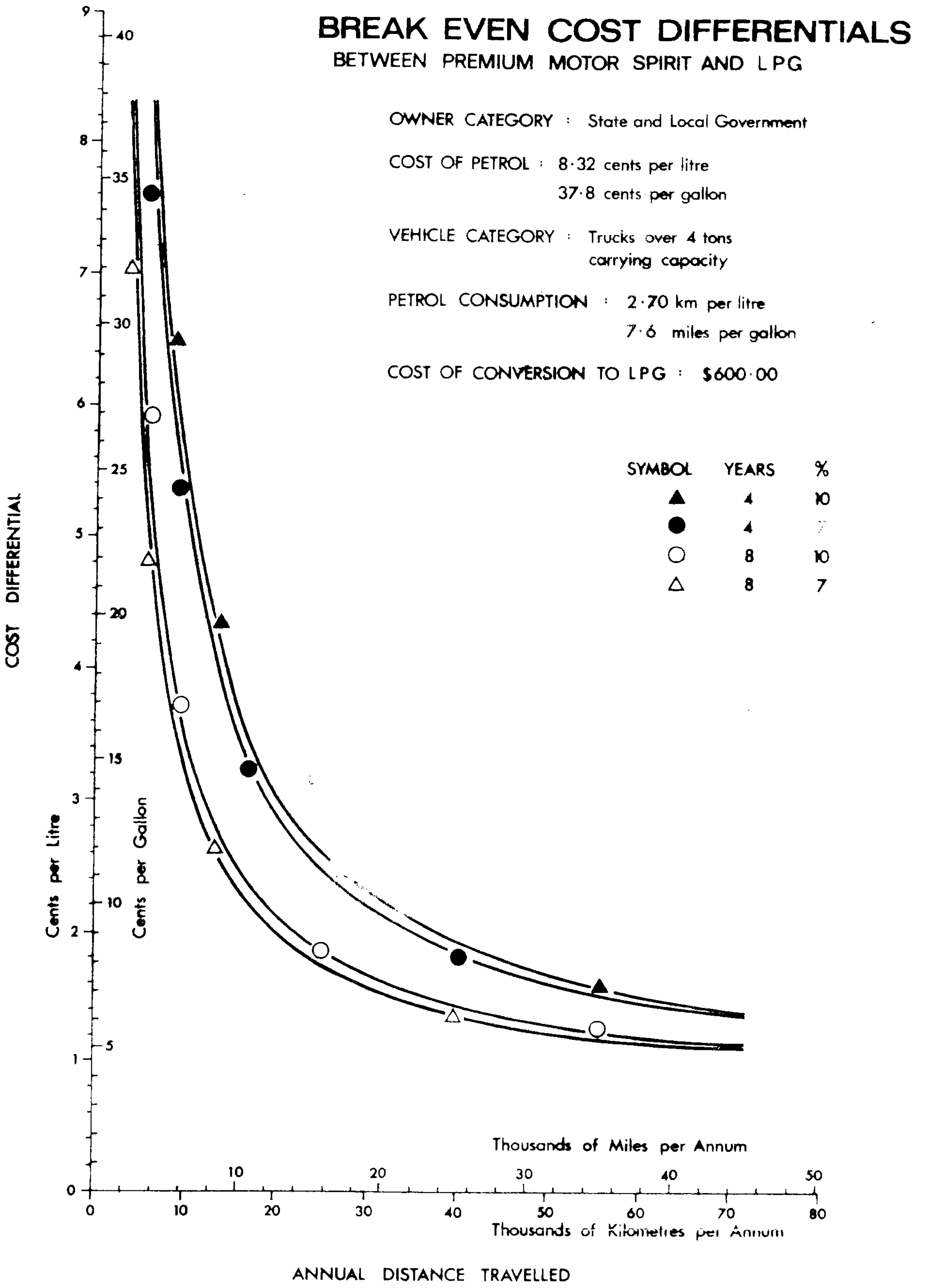
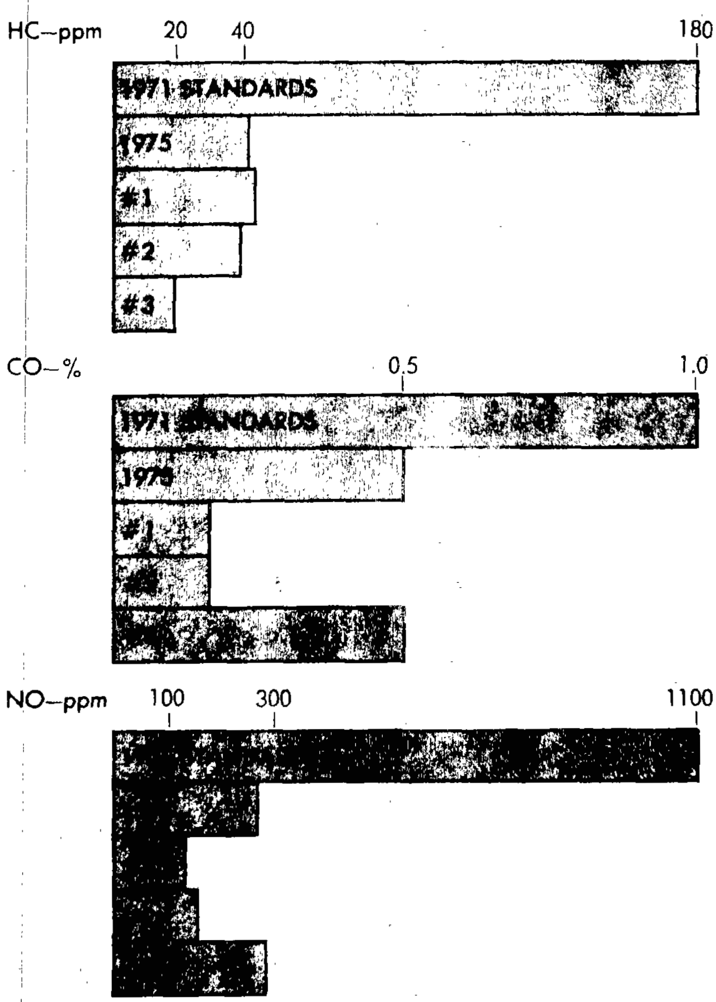

BREAK EVEN COST DIFFERENTIALS
BETWEEN PREMIUM MOTOR SPIRIT AND LPG
OWNER CATEGORY : State and Local Government
COST OF PETROL : 8·32 cents per litre
37·8 cents per gallon
VEHICLE CATEGORY : Trucks over 4 tons carrying capacity
PETROL CONSUMPTION : 2·70 km per litre
7·6 miles per gallon
COST OF CONVERSION TO LPG : $600·00
SYMBOL YEARS %
▲ 4 10
● 4 7
○ 8 10
△ 8 7
COST DIFFERENTIAL
Cents per Litre
Cents per Gallon
Thousands of Miles per Annum
Thousands of Kilometres per Annum
ANNUAL DISTANCE TRAVELLED

FIGURE 4

3 propane powered vehicles tested according to 1971 and 1975 standards by the State of California Air Resourses Board showed these results:

#1
1969 Chevrolet 350 V8
Impco Carburetion—4BBL
#2
1970 Chevrolet 350 V8-L56
Impco Carburetion—4BBL
#3
* 1965 Oldsmobile 425 V8
Impco Carburetion—2BBL



Tested 2-19-70

*NOTE: Test vehicle #3 had over 131,000 miles on propane with no engine overhaul and was under 1974 emission standards.

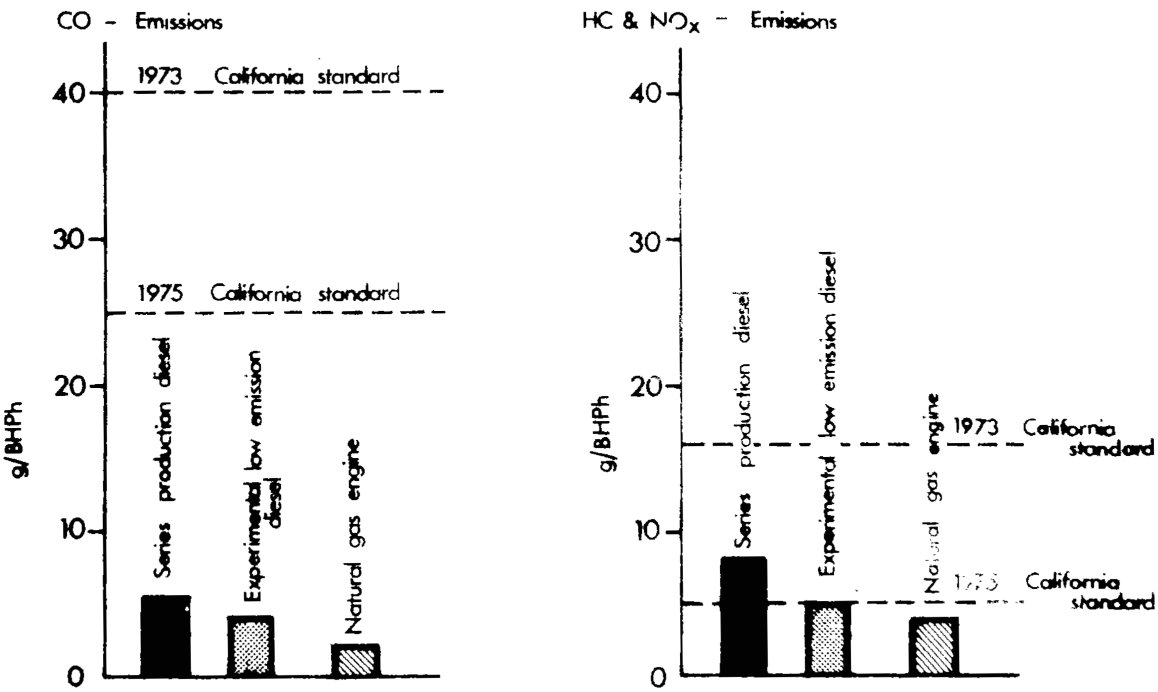
COMPARISON BETWEEN LPG VEHICLES AND CALIFORNIA EMISSION STANDARDS

Source: Petrolane Company, 1600 Hill Street, Long Beach, California, U.S.A.

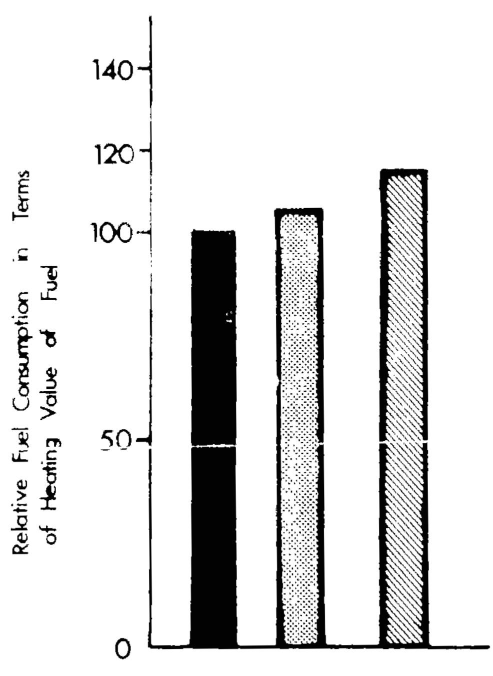
FIGURE 5

EMISSIONS - DIESEL AND NATURAL GAS ENGINES

a. COMPARISON OF EMISSIONS

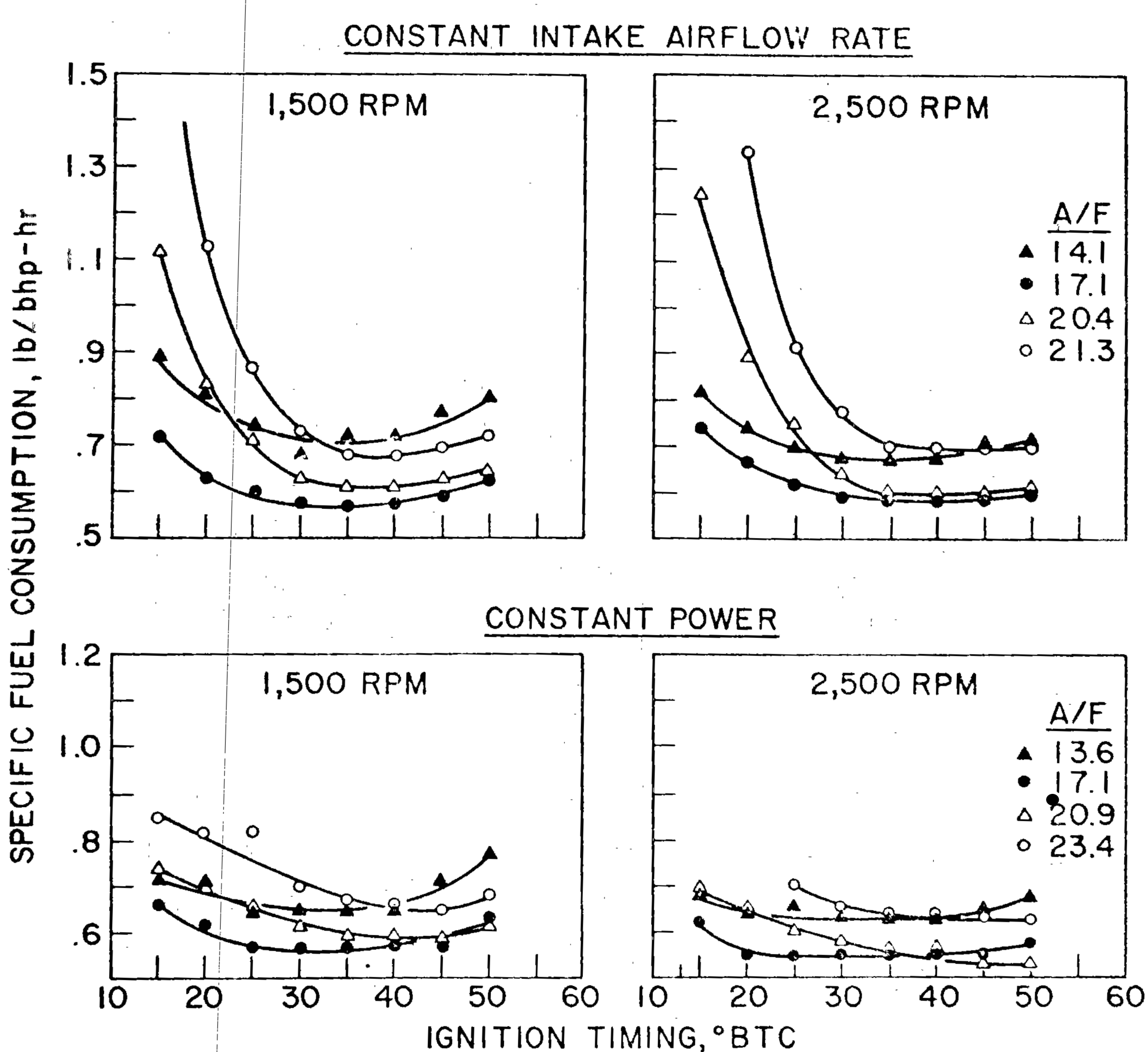


b. COMPARISON OF THE FUEL ECONOMY OF THE THREE ENGINES AS MEASURED BY THE RELATIVE CONSUMPTION OF FUEL ENERGY



Source : Daimler-Benz Aktiengesellschaft, Stuttgart, F.R. Germany

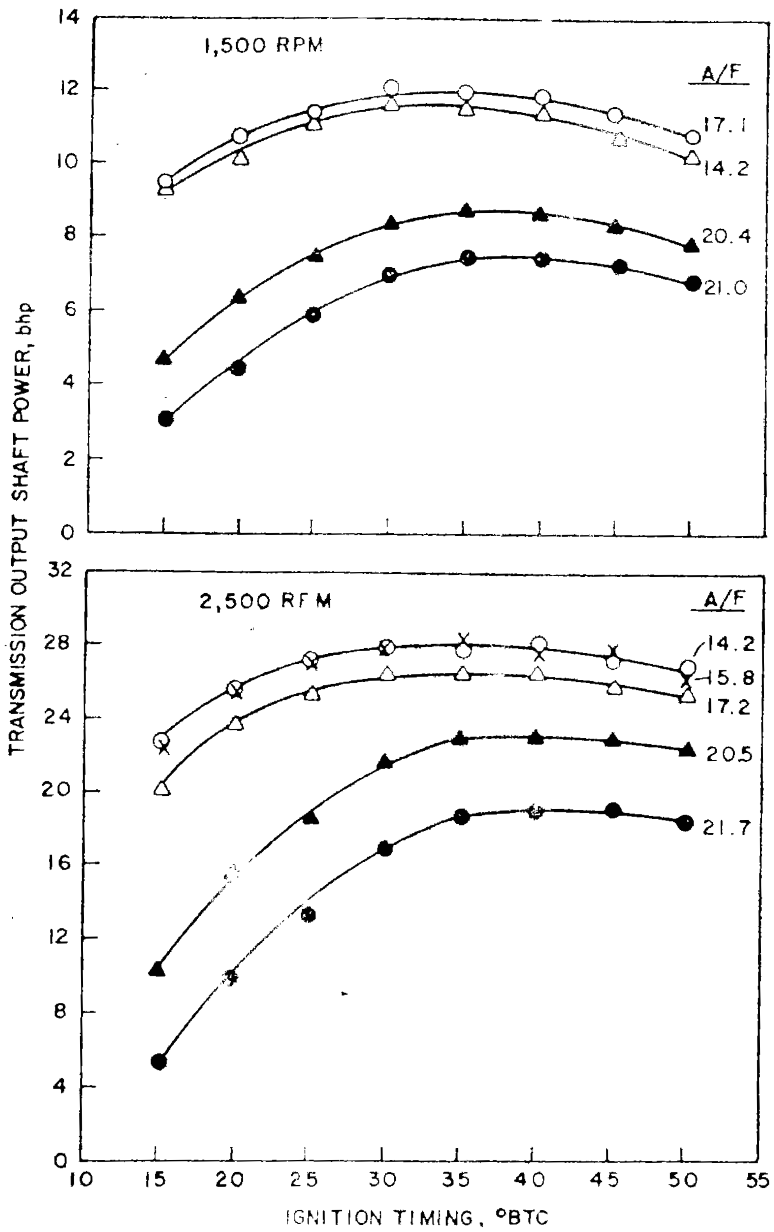
FIGURE 6



Effect of Ignition Timing and A/F on Specific Fuel Consumption.
1969 Chevrolet 327-CID engine; propane fuel.

Source: Allsup, J.R. and Fleming, R.D., Emission Characteristics of Propane as Automotive Fuel, Bureau of Mines, U.S. Dept. of the Interior.

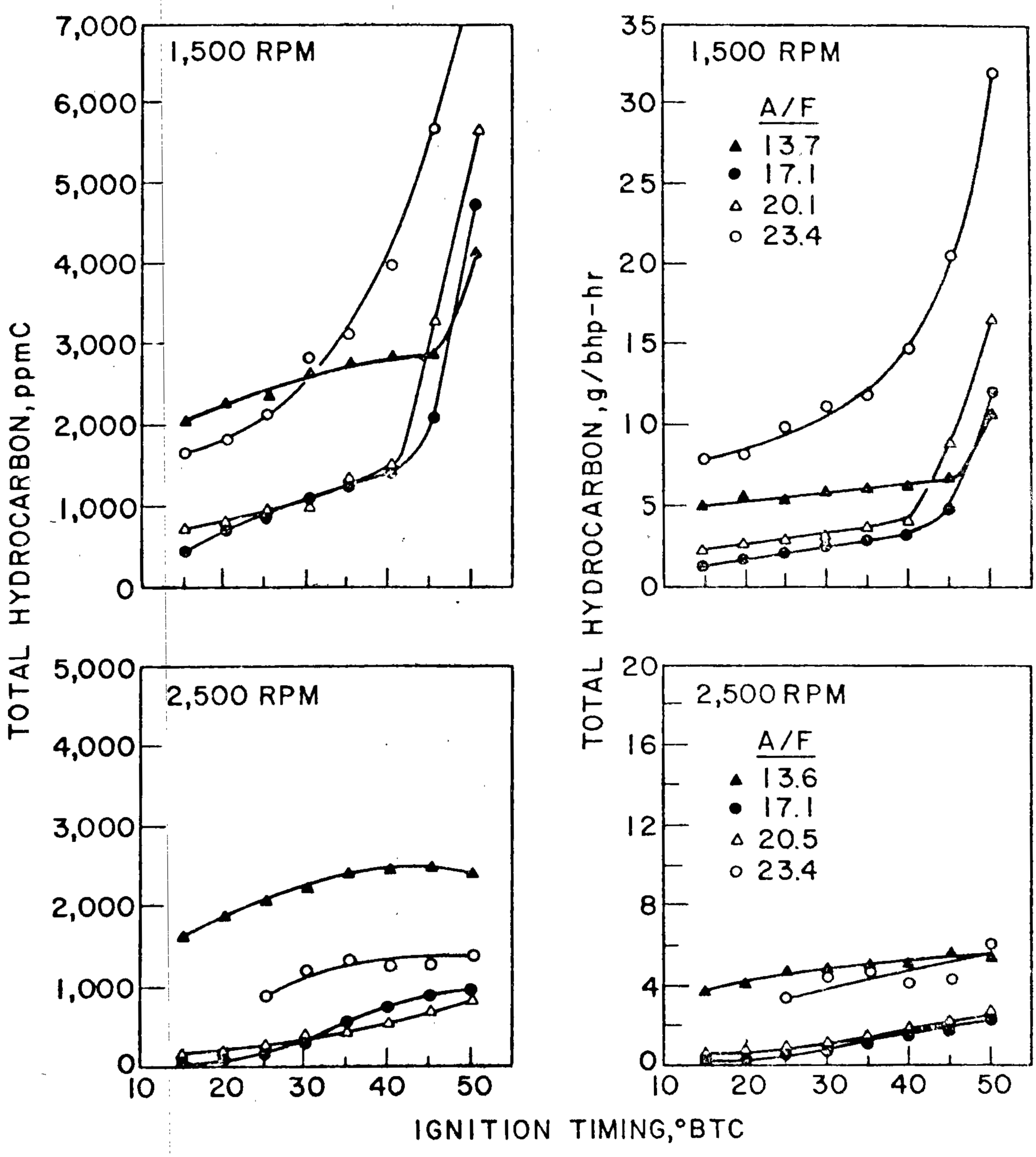
FIGURE 7



Effect of Ignition Timing and A/F on Power Output at Constant Intake Airflow Rate. 1969 Chevrolet 327-CID engine; propane fuel.

Source: Allsup, J.R. and Fleming, R.D., Emission Characteristics of Propane as Automotive Fuel, Bureau of Mines, U.S. Dept. of the Interior.

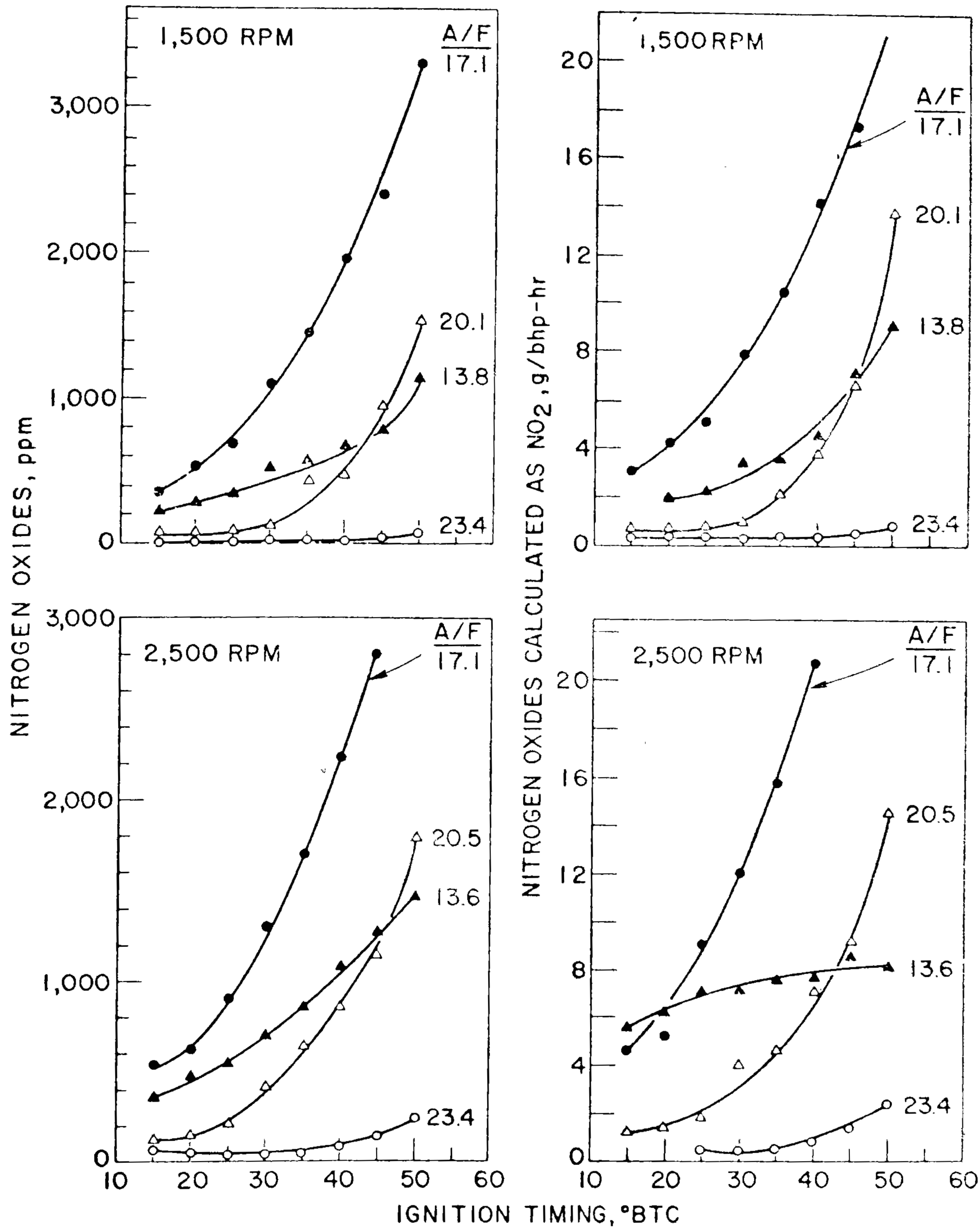
FIGURE 8



Effect of Ignition Timing and A/F on Hydrocarbon Emissions at Constant Power. 1969 Chevrolet 327-CID engine; propane fuel.

Source: Allsup, J.R. and Fleming, R.D., Emission Characteristics of Propane as Automotive Fuel, Bureau of Mines, U.S. Dept. of the Interior.

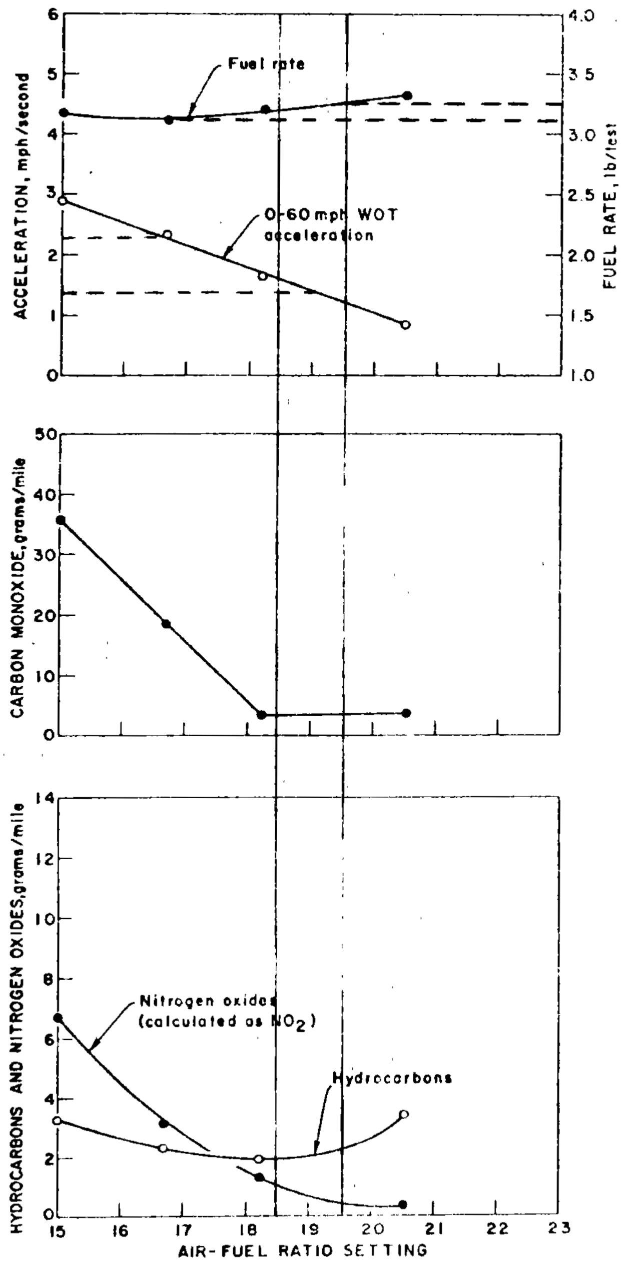
FIGURE 9



Effect of Ignition Timing and A/F on NO_x Emissions at Constant Power.
1969 Chevrolet 327-CID engine; propane fuel.

Source: Allsup, J.R. and Fleming, R.D., Emission Characteristics of Propane as Automotive Fuel, Bureau of Mines, U.S. Dept. of the Interior.

FIGURE 10



Performance and Emissions of CO, HC, and NO_x as a Function of A/F Setting. 1968 Chevrolet 327-CID engine; standard-ignition timing schedule; 7-mode cycle; propane fuel.

<u>Source</u>: Allsup, J.R. and Fleming, R.D., <u>Emission Characteristics of Propane as Automotive Fuel</u>, Bureau of Mines, U.S. Dept. of the Interior.