# Transport and Energy in Australia
# Part 1 - Review

## Occasional Paper

This report contains a survey of recent Australian and overseas literature on the availability and use of energy for transport. This study is provided with a view to improving the basis for decisions on energy supply, demand and price, on transport regulation and on the development of transport technology.

BUREAU OF TRANSPORT ECONOMICS

# TRANSPORT AND ENERGY IN AUSTRALIA

## PART 1 - REVIEW

NICHOLAS CLARK AND ASSOCIATES

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# FOREWORD

Rising fuel prices and widespread concern about the long-term availability of energy are serious matters for transport. Thus, the Bureau of Transport Economics has begun a thorough study of energy used in transport, with a view to improving the basis for decisions on energy supply, demand and price, on transport regulation and on the development of transport technology.

The first phase of this examination, a review of recent Australian and overseas literature directly relevant to the study, has been carried out for the BTE by Nicholas Clark and Associates. The results are contained in this report.

The BTE does not necessarily accept the findings of the consultant's report, but considers that the information will be useful to many people concerned with energy for transport.

J.H.E. Taplin
Director

Bureau of Transport Economics
Canberra
April 1975

# NICHOLAS CLARK AND ASSOCIATES

Dr. J.H.E. Taplin,
Director,
Bureau of Transport Economics,
CANBERRA.

Dear Dr. Taplin,

I have pleasure in forwarding to you our report on Transport and Energy - Literature Review. The report contains a survey of recent Australian and overseas literature on the availability and use of energy for transport.

Overall we found, despite the importance of transport movements in the use of energy, particularly energy derived from petroleum, that the literature on this subject was deficient in many respects. Very little published information relevant to Australia exists, and that published overseas, generally relating to the United States, often provides at best an obscure picture of the situation.

There are some differences of great importance in the availability of energy and its use for transport between Australia and the United States and, *a fortiori*, European countries. We suggest that further examination of this problem for Australian conditions is a worthwhile and feasible task.

I would like to emphasise that this report is based only on available published reports. As mentioned above these reports can scarcely be regarded as providing a satisfactory coverage of the subject of transport and energy. Our report, as a consequence, does not cover the subject in full detail.

Yours sincerely,

for Nicholas Clark and Associates.

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# CHAPTER 1 INTRODUCTION

The transport industry in Australia accounts for a significant proportion of both gross national product and total energy consumption. It is considered to contribute approximately 9% of the gross national product at factor cost, but because of the difficulties of measuring the contribution of ancillary and private transport movements, the share of GNP is probably significantly in excess of this figure. It is also attributed a 12% share of gross national expenditure but, again, contributes a portion in excess of this figure because of the manner in which the current system of national accounting treats personal investment in private transport vehicles.

Australian primary energy consumption in 1970-71 was about $2200 \times 10^{12}$ kJ, of which approximately 26.4% is commonly attributed to the transport sector. Once more, the transport share is probably greater than this, as will be shown below. Nevertheless, the figures do establish the order of magnitude of the role of the transport sector in the national and energy economies. They are, however, of little use in determining priorities and policies with regard to transport's consumption of scarce energy resources without further analysis of the fuels which it consumes and the task which it performs; these matters are discussed in detail in the body of the report.

The material reviewed in this report can be said to fall into two categories: statistical data published by the authorities and organisations responsible for the supply of energy in its various forms and for the regulation and administration of the transport industry; and a number of publications which interpret these statistics for the purposes of academic study or policy review. No original analysis is presented, but where the literature is seen to be deficient, every attempt has been made to outline the basis and procedures for possible later analyses.

## CHAPTER 2 THE SUPPLY OF ENERGY IN AUSTRALIA

Energy is not an abstract, universally available commodity. It is derived from raw materials found in the earth's crust or its atmosphere, and in most cases these raw fuels must be subject to a process which converts them into more manageable forms.

The fuels which are used to derive energy are numerous and various. It is important to distinguish between primary sources of energy and those which are derived from the processes above which convert primary input fuels into more convenient energy forms, the latter being called secondary energy sources. In this report, primary energy sources are assumed to comprise solid fuels (e.g., black coal, brown coal), liquid fuels (e.g., crude oil and natural gas liquids), and natural gases. Secondary or processed energy forms include thermal and hydro-electricity, manufactured gas, motor spirit, brown coal briquettes, etc.

It is also important to recognise, however, that certain of the resources utilised for producing energy do, in fact, have other uses (for example, crude oil is an important raw material for the petrochemical industry in the production of plastics) and that energy forms may in certain circumstances be substituted for one another (vehicles, for example, may be powered by electric batteries in place of petrol engines). These are significant considerations, the importance of which is indicated later in the report.

### SOURCES OF PRIMARY ENERGY

Table 2.1 shows various estimates of the consumption of primary energy in Australia for the year 1970-71, and indicates the component contributions made by the different energy sources. In Table 2.2, more recent estimates of the respective shares by the Department of Minerals and Energy are shown for 1971-72. The importance of crude oil as a source of energy in Australia is clearly illustrated. Almost 50% of the national energy consumption is derived from this source.

TABLE 2.1 - ESTIMATES OF PRIMARY ENERGY CONSUMPTION IN AUSTRALIA, 1970-71

| Fuel | Energy consumption (a) | | Energy consumption (b) | | Energy consumption (c) | |
|---|---|---|---|---|---|---|
| | $10^{12}$ kJ | % | $10^{12}$ kJ | % | $10^{12}$ kJ | % |
| Black coal | 656.3 | 30.2 | 698.7 | 30.6 | 653.8 | 30.6 |
| Brown coal | 227.9 | 10.5 | 243.5 | 10.6 | 227.8 | 10.7 |
| Crude oil | 1048.0 | 48.1 | 1139.2 | 49.8 | 1066.0 | 49.9 |
| Natural gas | 73.2 | 3.4 | 78.1 | 3.4 | 73.1 | 3.4 |
| Firewood and Bagasse[(d)] | 15.6 | 0.7 | 80.6 | 3.5 | 75.4 | 3.5 |
| Hydro-electricity[(e)] | 155.6 | 7.1 | 45.1 | 2.0 | 42.2 | 2.0 |
| Total | 2176.6 | 100.0 | 2285.2 | 100.0 | 2138.4 | 100.0 |

(a) Source: Joint Coal Board (Ref. 45).

(b) Source: Dept. of National Development (Ref. 27).

(c) Source: Gartland (Ref. 35).

(d) Bagasse is a fuel derived from waste sugar cane pulp.

(e) The Joint Coal Board calculates the equivalent of hydro-electricity as the coal required to generate a similar quantity of electricity in conventional thermal power stations (37.5% efficiency). The other sources have used the direct heat value of the generated hydro-electricity.

TABLE 2.2 - RELATIVE SHARES OF THE AUSTRALIAN ENERGY MARKET SUPPLIED BY EACH MAJOR FUEL TYPE, 1971-72

| Fuel | % |
|---|---|
| Petroleum products | 49.5 |
| Black coal | 29.8 |
| Brown coal | 10.6 |
| Natural gas | 4.5 |
| Bagasse | 2.0 |
| Hydro-electricity | 1.9 |
| Wood | 1.7 |

Source: Department of Minerals and Energy (Ref. 25).

Historical trends in the consumption of primary energy are shown in Figure 2.1, which indicates the gross national consumption and the component contributions of various fuel sources. It should be noted that the data are presented on an equivalent thermal basis, even though most fossil fuels are converted to some alternative secondary form of energy before final utilisation in the production of useful work. Each of these conversion processes involves energy losses, a matter which is considered below.

It is apparent from Figure 2.1 that total primary energy consumption in Australia has been growing over the past decade with a fairly constant rate of increase of about 6% per annum. The forecasts of the Department of Minerals and Energy, shown in the diagram, are based on a continuation of this rate of increase, implying an assumption of a continuing close correlation of energy consumption and Gross National Product, discussed elsewhere in this report, and stable population growth trends (see McCay and Deas (Ref. 50) for a discussion of the underlying assumptions).

Petroleum's share of total energy consumption may be seen from Figure 2.1 to be increasing, and that of wood and

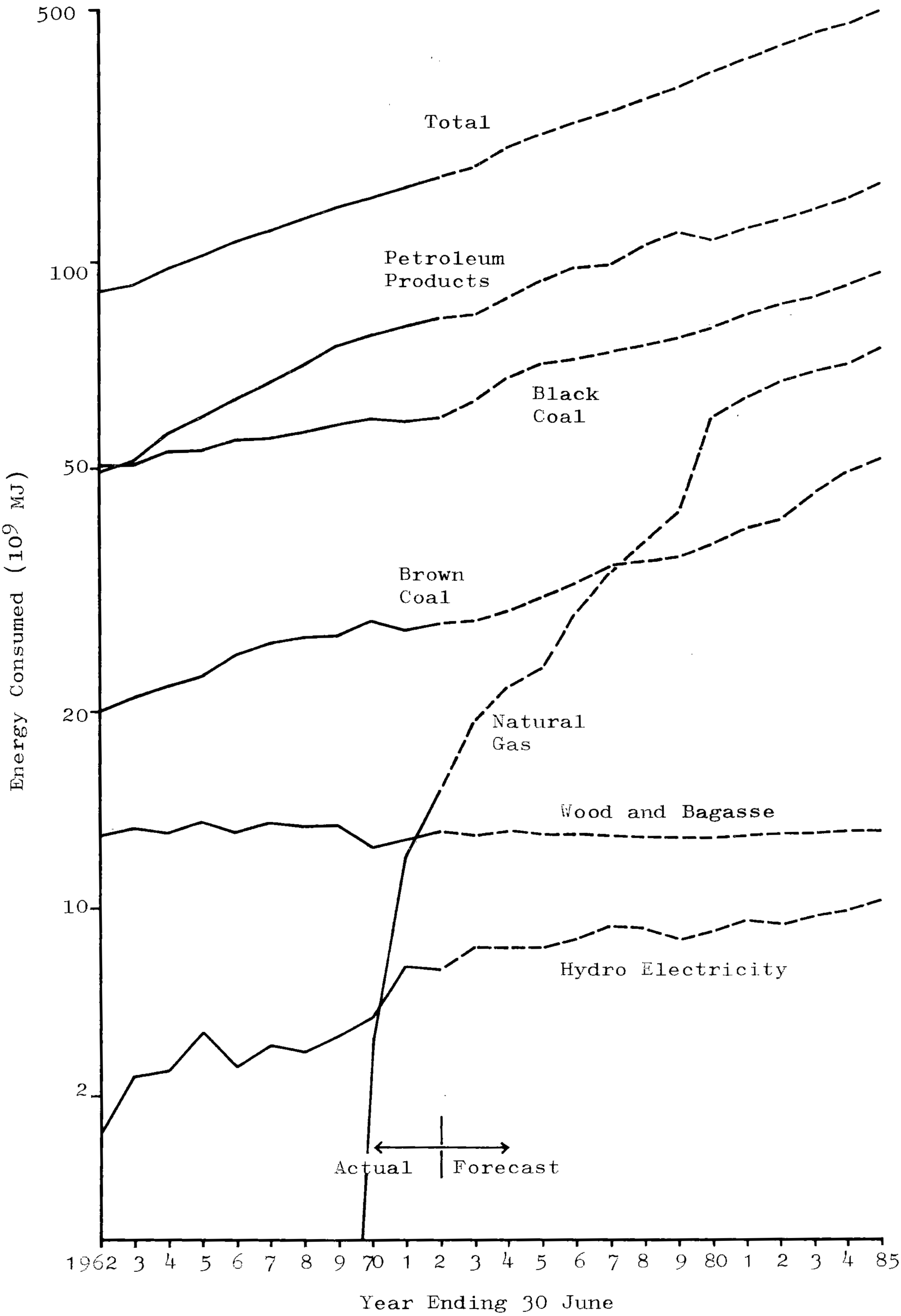



FIGURE 2.1 - CONSUMPTION OF PRIMARY FUELS, AUSTRALIA, BY FUEL TYPE

Source: Department of Minerals and Energy (Ref. 25) bagasse to be declining. Natural gas, a recent discovery in Australia, is dramatically increasing its share of the market. The other sources of primary energy, coal and hydro-electricity, are expended at an increasing rate in line with the growth of total energy consumption.

Not unnaturally, the pattern of energy usage within individual States has been dependent on the proximity of fuel deposits to population centres, and the choice of fuel, particularly for electricity generation, has been based almost entirely on local economic considerations (Ref. 36). Thus, the present importance of black coal to New South Wales and Queensland, of brown coal to Victoria, and of hydro-electric power to Tasmania are clearly illustrated in Figure 2.2, a comparison of the relative importance of different fuels in the six States for the year 1970-71 (note that consumption figures are quoted in terms of black coal equivalent).

The total energy consumption of each State is compared in Table 2.3, which also shows the population of each State; the close correlation of energy consumption and population is obvious. Each State's share of national primary energy consumption is almost directly related to its share of the national population. The energy consumed per head of population in each State in 1970-71 is almost the same: approximately 160-170 million kJ, double that consumed per capita in 1945.

## ENERGY RESOURCES

Reviews of Australia's energy resources have been presented in a number of publications (for example, Refs. 27, 36 and 50). It is sufficient here only to discuss in general terms the availability and distribution of the more important of Australia's energy reserves, rather than attempt to put a figure to them, mainly because of the difficulties which arise in determining the actual extent of existing reserves. With exploration and production largely in the hands of the private sector of the economy, energy reserves will almost certainly not be found or developed until it can be shown that they contribute

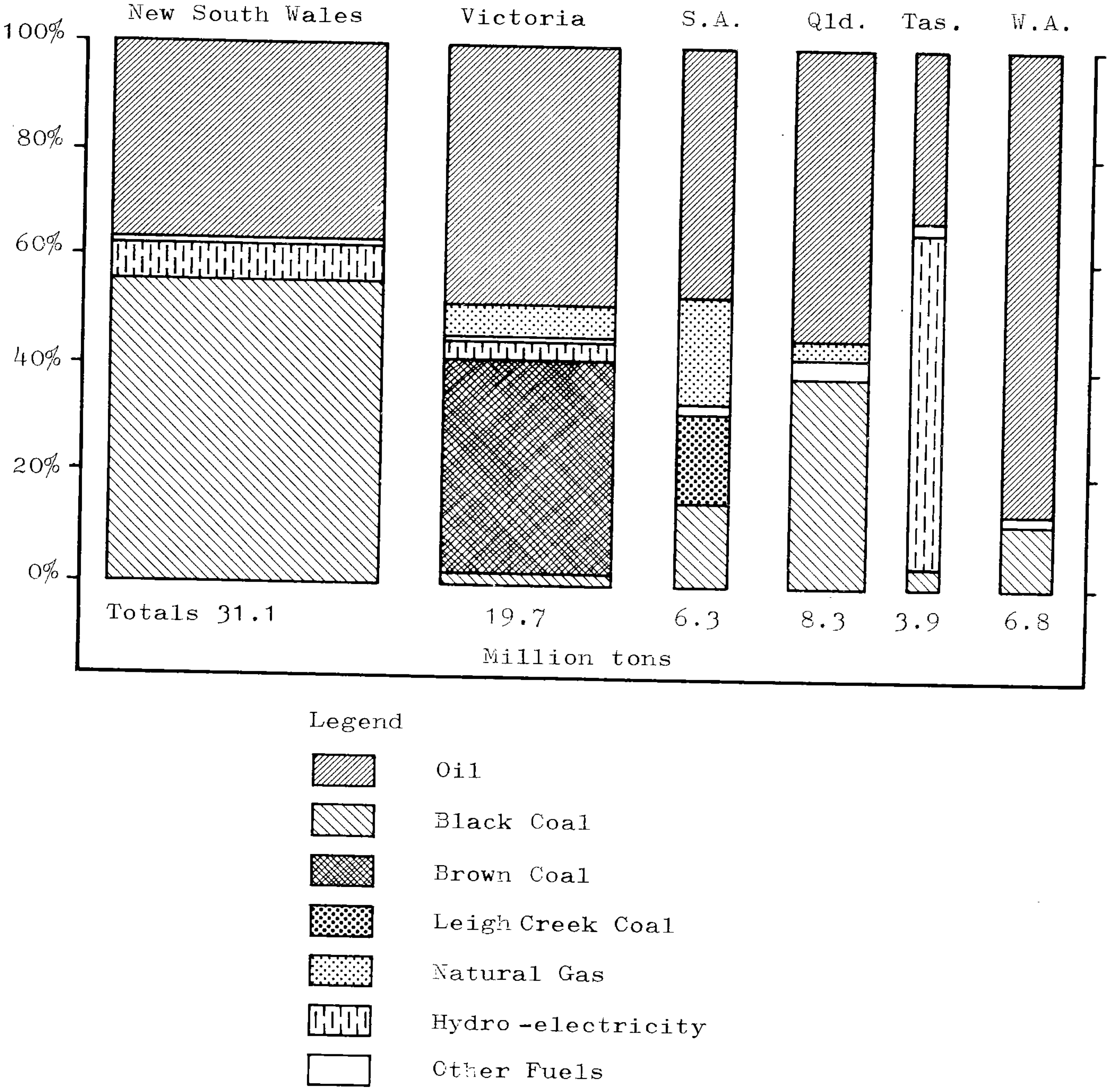



FIGURE 2.2 - CONSUMPTION OF PRIMARY ENERGY BY STATES, 1970-71

Source: Joint Coal Board (Ref. 45)

TABLE 2.3 - CONSUMPTION OF PRIMARY ENERGY, BUNKERS AND POPULATION BY STATES 1970-71 (Quoted in Kalma and Aston, Ref. 47)

| State | Use of primary energy excl. bunkers[a] | | Use of primary energy excl. bunkers[b] | | Bunkers (c) | Population | |
|---|---|---|---|---|---|---|---|
| | $10^{12}$ kJ | % | $10^{12}$ kJ | % | $10^{12}$ kJ | $10^3$ | % |
| New South Wales (incl. ACT) | 803 | 40.9 | 825 | 40.2 | 30 | 4708 | 37.4 |
| Victoria | 528 | 26.9 | 536 | 26.1 | 24 | 3449 | 27.4 |
| South Australia | 176 | 9.0 | 182 | 8.9 | 3 | 1165 | 9.3 |
| Queensland | 225 | 11.4 | 264 | 12.9 | 6 | 1802 | 14.3 |
| Tasmania | 58 | 3.0 | 63 | 3.1 | 2 | 393 | 3.1 |
| Western Australia | 161 | 8.2 | 167 | 8.1 | 33 | 983 | 7.8 |
| Northern Territory | 13 | 0.7 | 14 | 0.7 | 1 | 72 | 0.6 |
| Total Australia | 1964 | 100.0 | 2051 | 100.0 | 99 | 12573 | 100.0 |

(a) Source: Joint Coal Board (Ref. 45).

(b) Source: Fryer (Ref. 34).

(c) Source: Petroleum Information Bureau (Ref. 57).

towards profitable commercial operations within the horizon of current investment strategies. Known reserves are only working inventories. They simply represent the extent of the resources necessary to ensure continuation of production over the adopted financial investment period.

It is, thus, quite meaningless to postulate that at current rates of consumption, Australia's known reserves of crude oil, for instance, will run out in 'x' years. It is probable that reserves of oil in the Bass Strait extend to multiples of current known or proven reserves, but are currently not worth the expense of exploration since more accessible reserves have already been shown to be available.

Table 2.4 summarises Australia's known recoverable energy resources (from Ref. 36), but the reader should be forewarned of the danger in interpreting the figures in the light of the preceding discussion.

## Coal

Estimates of Australia's reserves of black and brown coal which can be economically recovered differ considerably but are unanimous in their indication of abundance. Black coal production in Australia for all purposes in 1960-61 was 23 million tonnes and had more than doubled to 51 million tonnes in 1970-71. At the same time, the percentage exported had increased from 9% in 1960-61 to almost 40% in 1970-71. It is unlikely that indicated reserves of economically recoverable black coal will be exhausted in less than 100 years at the very least.

The picture is equally dramatic for brown coal. Measured and indicated (i.e., proven) reserves exceed $50 \times 10^9$ tonnes and the possible tonnage may be $100 \times 10^9$ tonnes, of which some $20 \times 10^9$ tonnes are currently economically recoverable. If the present rate of consumption, around $23 \times 10^6$ tonnes per annum, remains stable (it is proposed that the new 1000 MW Newport power station in Victoria should operate on natural gas and other applications of brown coal have shown a decline in recent years) the brown coal would last for 1000 years (Ref. 36).

TABLE 2.4 - SUMMARY OF AUSTRALIA'S KNOWN RECOVERABLE PRIMARY ENERGY RESOURCES, 1972

| Resources | | Reserves | | Gross Energy Equivalence ($kJ \times 10^{15}$) |
|---|---|---|---|---|
| COAL | Black: | NSW | $7231 \times 10^6$ tonnes | |
| | | Qld. | $5091 \times 10^6$ tonnes | |
| | | Other | $481 \times 10^6$ tonnes | |
| | | Total | $12803 \times 10^6$ tonnes | 300 |
| | Brown: | Vic. | $20320 \times 10^6$ tonnes | 200 |
| OIL | | Vic. | $1590 \times 10^6$ barrels | |
| | | NT | $300 \times 10^6$ barrels | |
| | | WA | $200 \times 10^6$ barrels | |
| | | Other | $20 \times 10^6$ barrels | |
| | | Total | $2110 \times 10^6$ barrels | 10 |
| NATURAL GAS | | WA | $560 \times 10^9$ $m^3$ | |
| | | Vic. | $196 \times 10^9$ $m^3$ | |
| | | Other | $196 \times 10^9$ $m^3$ | |
| | | Total | $952 \times 10^9$ $m^3$ | 36 |
| URANIUM | | NT | 64400 tonnes $U_3O_8$ | |
| | | WA | 45500 tonnes $U_3O_8$ | |
| | | Qld. | 14500 tonnes $U_3O_8$ | |
| | | Other | 4500 tonnes $U_3O_8$ | |
| | | Total | 128900 tonnes $U_3O_8$ | 60 (or 6000 with breeding) |

Sources: Coal - Australian Bureau of Mineral Resources (Ref. 2).
Oil - Petroleum Information Bureau (Ref. 57).
Natural gas - Conyboare (Ref. 19) - with updating for North Rankin.
Uranium - AAEC (Ref. 1) - with updating for Yeelirrie.

## Petroleum

Under this general heading are included crude oil, condensate and natural gas. Apart from the statistical sources in the literature, of which the most useful is Petroleum Information Bureau (Ref. 57), there are a number of texts available which provide more detailed descriptions of the industry, its prospects for development, and its historical growth and operations (for example, Refs. 19, 27, 34, 54 and 55).

The abundance of natural gas deposits in Australia is illustrated in Table 2.4. The outstanding natural gas potential of the north-west shelf region, off the coast of Western Australia, with proven reserves totalling $560 \times 10^9$ $m^3$, confirms the importance of this source of energy in Australia's future.

The natural gas so far discovered in Australia is of a particularly high quality, with little or no sulphur compounds present (Ref. 58). The quality of domestic crude oil, however, varies somewhat with location (for details, see Refs. 19, 32, 49, 54 and 58), but in general it is low in specific gravity and is deficient in the heavier fractions required for heating diesel and lubricating applications. Because of this, although only 6.1% of 1971-72 consumption of motor spirit was not met by local refinery production, 21% of diesel fuel and fuel oil consumption had to be imported. Thus, of the total consumption of petroleum products (including natural gas) of $31.85 \times 10^9$ litres, only 87.5% was met by net Australian production (refinerY production less exports (Ref. 57).

## Uranium

Uranium is relevant to the extent that it is a possible primary source of fuel for the generation of electricity which may eventually provide power for electric vehicle traction.

Australia is one of the world's major sources of uranium. The value of and demand for uranium, on which economic recovery rates and the definition of resources depend, have been subject to considerable fluctuations in the past, but on the basis of a figure of $A22 per kg, the western world's total reserves have been estimated at $1.1 \times 10^6$ tonnes. Of these, Australia has reasonably assured resources of $84 \times 10^3$ tonnes $U_3O_8$ at less than $22 per kg, and a further $34 \times 10^3$ tonnes in the $22-$33 price range. Estimated additional resources in the two categories are $93 \times 10^3$ and $34 \times 10^3$ tonnes respectively, but these figures are very conservative and do not include the recent discovery of $45 \times 10^3$ tonnes at Yeelirrie or further discoveries in the Alligator Rivers field (Ref. 64, quoted in Ref. 36).

## Solar Energy

The use of solar energy as a means of supplementing the supply of power to the transport sector is considered in more detail in the section relating to new technologies. Solar flux is, however, a natural energy resource of some significance in Australia and should be briefly mentioned at this point. If all the technical and economic problems, including that of energy storage, can be overcome, an almost limitless energy source could be tapped. With a peak solar flux of 1 $kw/m^2$ and conversion efficiencies of say 20%, the land area required to supply all of Australia's current energy demand would be only 100 $km^2$ (Ref. 36).

## Hydro-power

Australia is not well endowed with hydro resources. Tasmania is the only State where a significant proportion of the total area (56%) receives an annual rainfall in excess of 1000 mm. It is estimated to have about half of the total Australian hydro potential of about 23,000 million kWh per annum capable of being developed economically (Ref. 50). Total installed hydro capacity in Australia was 4242 MW on 30 June 1972 (Ref. 29).

## Tidal power

Tidal power represents another possible energy resource. The bays and estuaries of the Kimberley area of north-west Australia are estimated to have a tidal potential of some 300,000 MW at 50% load factor (Ref. 50). Exploitation of the resource is not imminent principally because of the vast distances separating the area from major load centres. Its development might, however, be undertaken in association with mineral developments in nearby areas.

ENERGY CONVERSION: SOURCES OF SECONDARY ENERGY

The form of fuel material derived directly from the earth's crust is in the majority of cases unsuitable for direct conversion into useful work. As far as energy in transport is concerned, motor spirit, diesel oil, electricity and coal are all energy forms which have been converted in one way or another from the original raw energy sources. Details of the processes which convert primary energy sources into more convenient forms of secondary energy are not needed here, but it is important to indicate that they themselves each involve some loss of energy.

Fryer (Ref. 34) presented a convenient pictorial representation of the conversion processes and their energy losses for the year 1968-69, reproduced in Figure 2.3. A similar analysis of energy use in the Sydney Statistical Division in 1970 was presented by Kalma et al (Ref. 47), and is summarised in Figure 2.4. The figures quoted by Fryer for the year 1968-69 indicate that some 27% of input primary energy is lost in the form of heat during the processes of conversion from primary energy to secondary energy (at oil refineries, gas works, briquette factories and power stations).

The national picture will, of course, have significantly altered since Fryer's study, and there is an obvious need for further analysis of the energy efficiencies of the conversion processes. The feasibility of new technologies of transport is influenced by the extent to which they make efficient use of available energy resources.

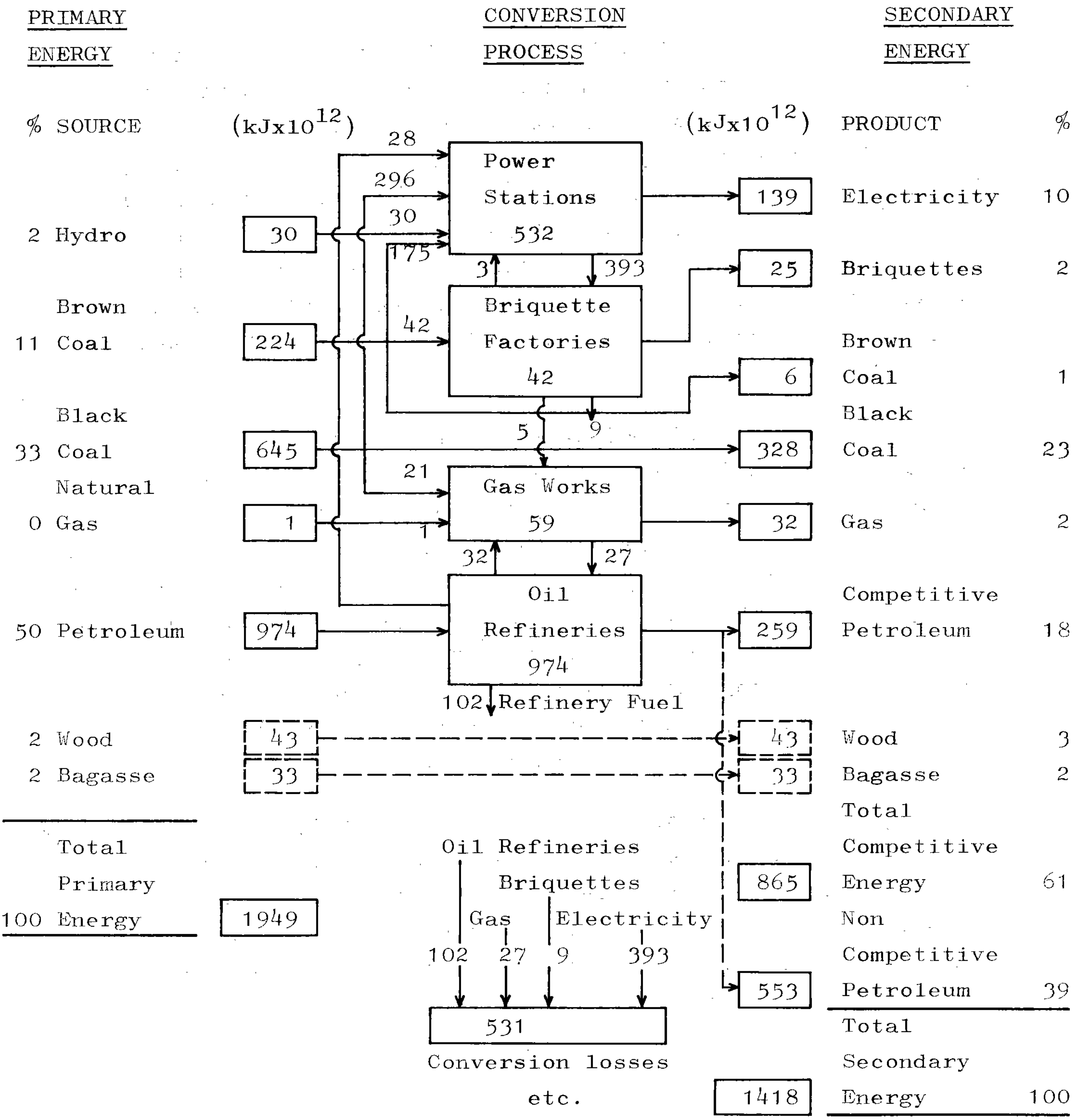



FIGURE 2.3 - AUSTRALIAN ENERGY CONSUMPTION AND CONVERSION PROCESSES. 1968-69

Source: Fryer (Ref. 34)

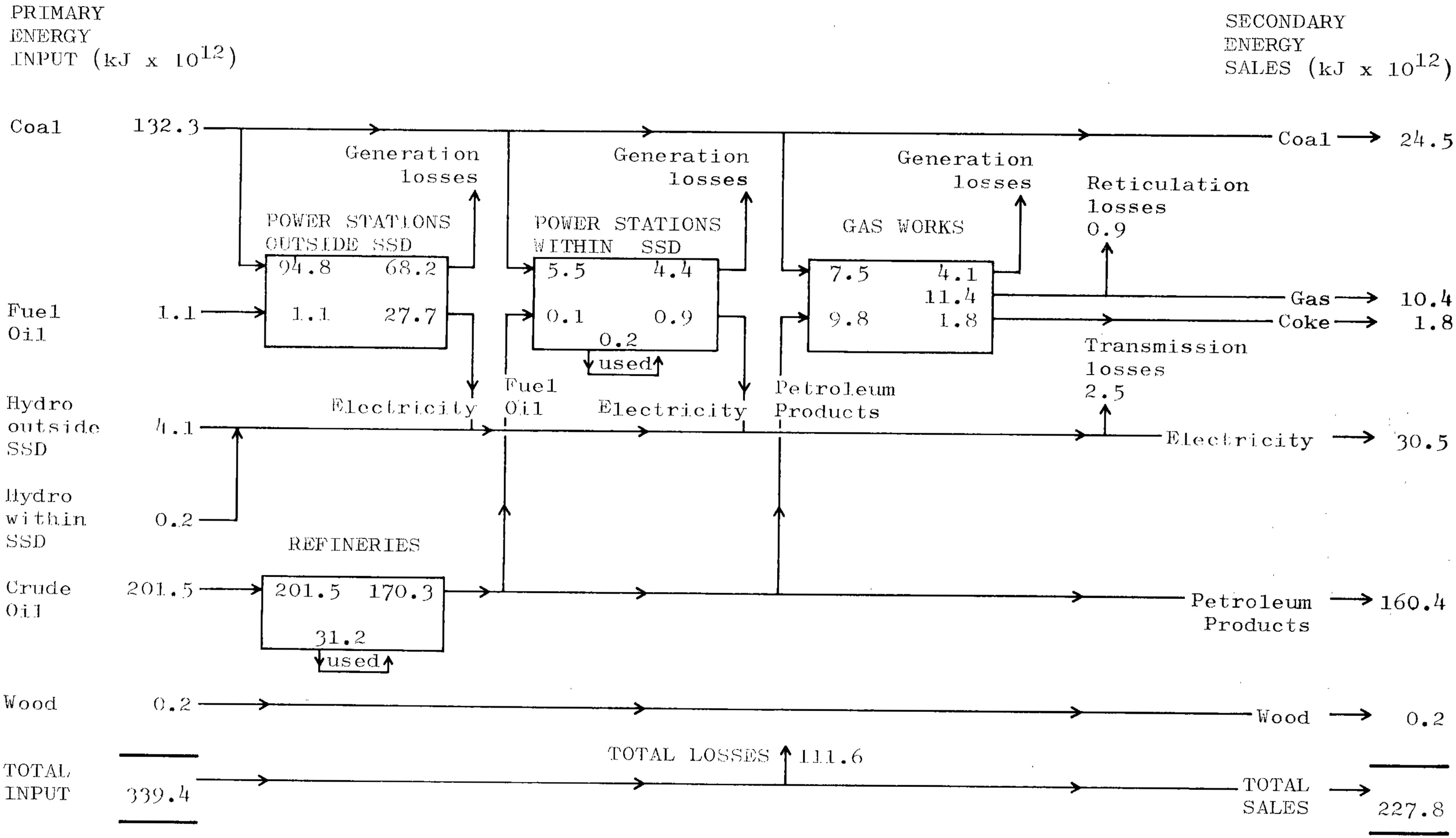



FIGURE 2.4 - ENERGY USE IN THE SYDNEY STATISTICAL DIVISION (SSD), 1970

Source: Kalma et al (Ref. 47)

## CHAPTER 3 ENERGY CONSUMPTION

### TRENDS IN THE NATIONAL CONSUMPTION OF ENERGY

Table 2.1 and Figure 2.1 detail the national consumption of primary fuels by fuel type. It has also been mentioned above that total primary energy consumption in Australia is growing at a reasonably constant rate of about 6% per annum. It is worth examining this consumption growth trend with a view to identifying the manner in which it may increase in future years.

McCay and Deas (Ref. 50) have described some of the assumptions behind the Government's predictions up to the year 2000. The forecasts up to 1980 assume that current economic trends will continue and that no dramatic changes in technology will occur. The effects of the construction of three new steel plants by 1980 have been incorporated as well as the introduction to Sydney of natural gas by 1974. Inter-fuel sharing of the market is predicted to change slightly in favour of natural gas at the cost of black coal, while petroleum products are expected to maintain their position.

Total primary energy use in Australia for 1970-71 was $2285 \times 10^{12}$ kJ. Projected use for 1979-80 is $3280 \times 10^{12}$ kJ and for 2000 about $11740 \times 10^{12}$ kJ. The Department of Minerals and Energy's forecasts to the year 2000 are shown in Table 6.1 (Chapter 6).

The assumed link between energy consumption and economic growth is an important one (see, for example, Refs. 10, 22 and 46). Darmstadter (Ref. 22) calculated energy use and GNP for 49 countries. The cross-sectional data, reproduced in Figure 3.1, shows clearly that the higher a nation's income or output per capita, the higher its use of energy.

Time trends in the ratio of energy use to GNP per capita have been studied by others (see, for example, Refs. 20 and 22). In Figure 3.2, reproduced from Ref. 46, such time trends for Australia and three other industrialised countries are compared.

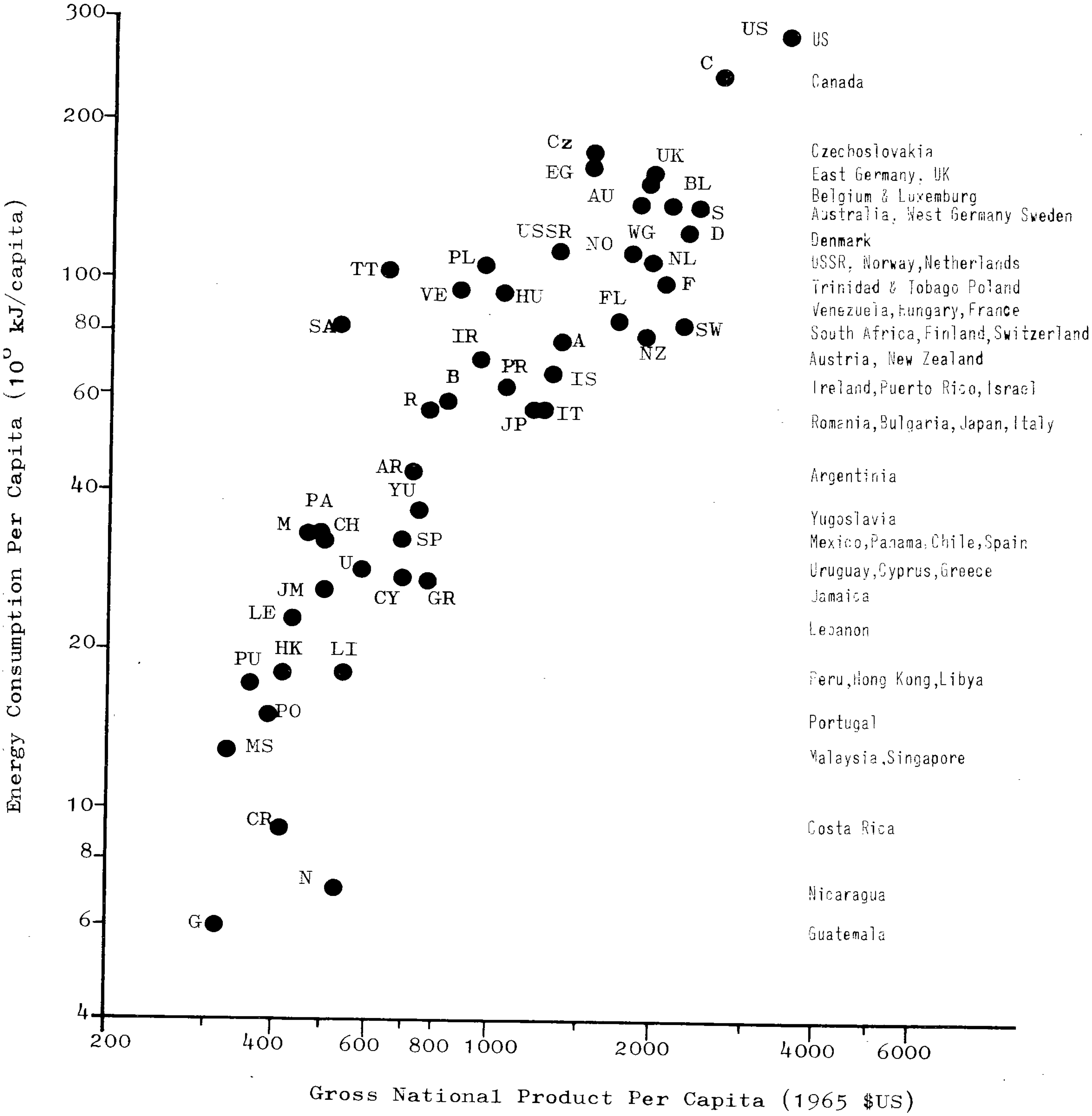



FIGURE 3.1. - CORRELATION BETWEEN PER CAPITA CONSUMPTION OF ENERGY AND PER CAPITA GROSS NATIONAL PRODUCT FOR 49 COUNTRIES

Source : Darmstadter (Ref. 22)

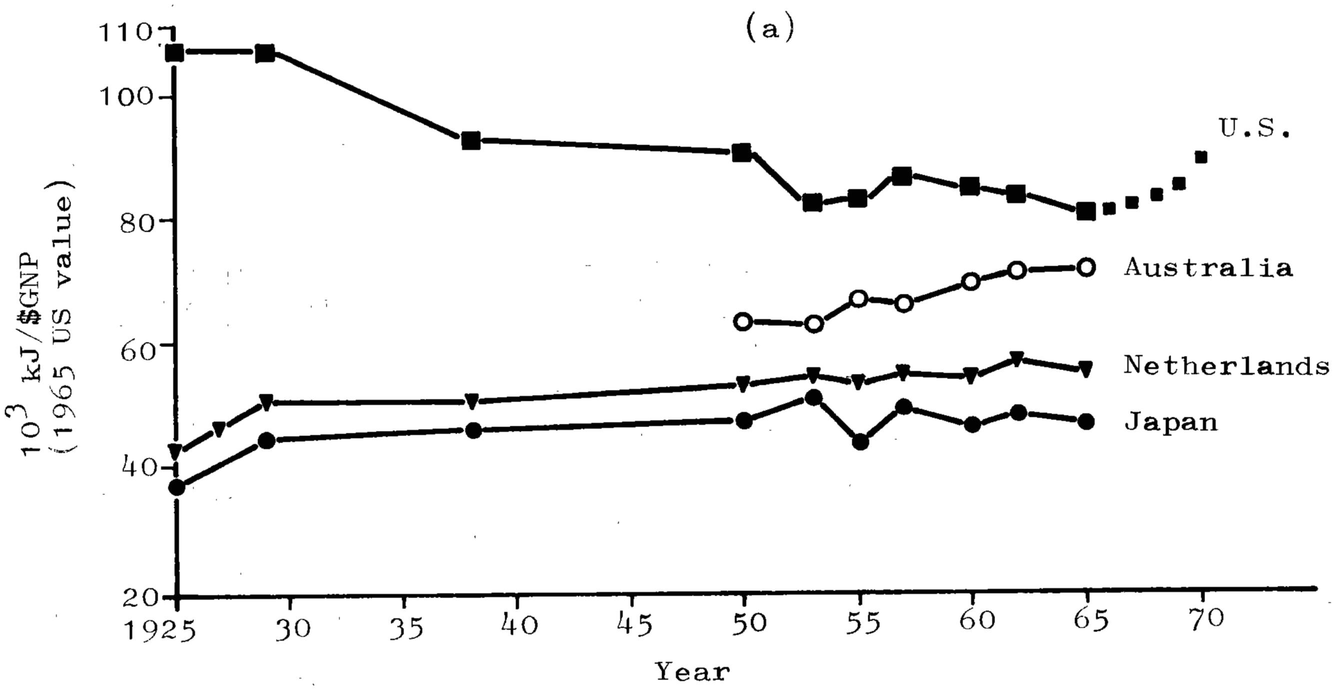



FIGURE 3.2(a) - RATIO OF ENERGY USE TO GNP FOR FOUR INDUSTRIALISED COUNTRIES

Source: 1925-1965 data from Darmstadter (Ref. 22)
1965-70 data from Cook (Ref. 20)


FIGURE 3.2(b) - RATIO OF ENERGY USE TO GNP FOR AUSTRALIA

Source: Calculated from data taken from CBCS (Ref. 18) and Department of National Development (Ref. 27)

They indicate that GNP (equivalent to total expenditure on final goods and services bought for use in the national economy, plus exports of goods and services, less imports of goods and services) is a reasonably reliable indicator of national energy consumption. Cognisance should be given, of course, to the problems involved in realistic measurement of both GNP and energy consumption.

The growth of energy per capita in Australia is further illustrated by Figure 3.3, which shows an increase of about $80 \times 10^6$ to $160 \times 10^6$ kJ/capita since 1945. The implications of this with regard to the transport sector are discussed later.

CONSUMPTION OF PRIMARY ENERGY BY SECTOR

A breakdown of the sectoral consumption of primary energy has been published by both Hayes (Ref. 39) and Department of National Development (Ref. 27). Of the total consumption in 1970-71 of about $2200 \times 10^{12}$ kJ, transport is said to use 26.4%, electricity generation 28.9%, agriculture 1.9%, remaining primary industry and secondary industry 38.3% and the domestic and commercial sector 4.5%. Of the total electricity generated ($1912 \times 10^{12}$ kJ), however, 37.0% was used in the domestic sector, 60.7% in the industrial and commercial sectors, 1.5% in traction and 0.8% in public lighting.

THE TRANSPORT SECTOR

It is quite obvious that the transport share of the aggregate consumption refers only to direct consumption by the domestic transport industry. Energy consumed by Australia's share of international transport has been ignored and consumption by certain other transport services are inevitably concealed within the figures for industrial and commercial use. The amount of energy consumed in, for instance, the manufacture, maintenance and distribution of motor vehicles, in road construction, maintenance and policing, in shipbuilding and in vehicle insurance and hospital services provided for vehicle accident victims should all ideally be identified and attributed to the transport sector.

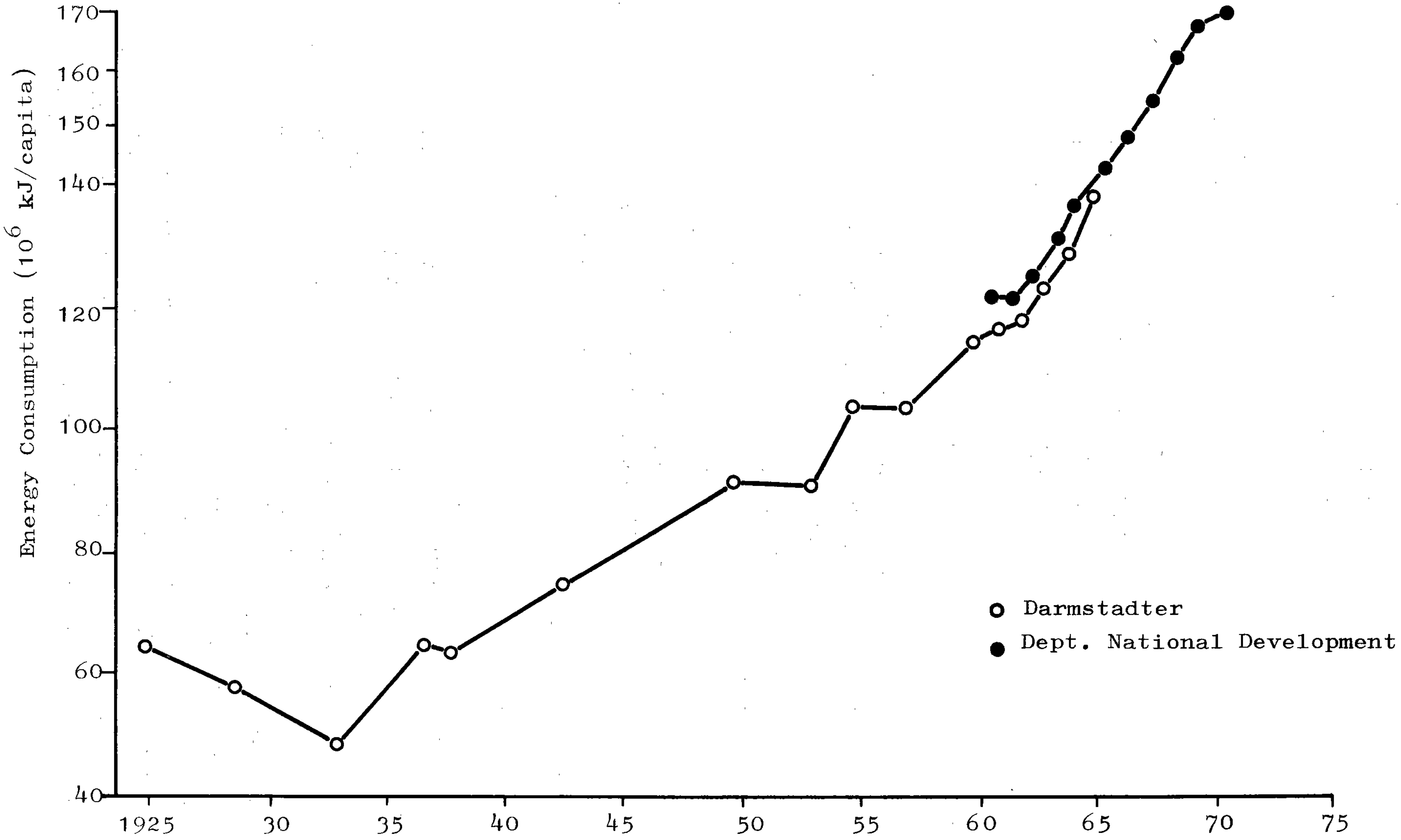



FIGURE 3.3 - PER CAPITA CONSUMPTION OF PRIMARY ENERGY IN AUSTRALIA

Sources : Darmstadter (Ref. 22), Department of National Development (Ref. 27)

These energy uses are referred to as indirect uses. In some cases, these contributions will be trivial; in others, of considerable significance. Putting a value to these, however, is no easy matter. Indirect energy consumption of this nature by the transport sector is discussed in more detail in Chapter 4.

## CHAPTER 4 ENERGY CONSUMPTION BY THE TRANSPORT SECTOR

Direct energy consumption by transport within Australia amounted to 583 x $10^{12}$ kJ in 1970-71, some 26.4% of the total national consumption. The corresponding figures for the US were 17900 x $10^{12}$ kJ and 25% (Ref. 28).

It was suggested earlier, however, that direct energy consumption represents only a part of the total amount of energy used in activities directly associated with transport. The balance, known as indirect energy consumption (for example, energy used in refineries, in the manufacture, sales and maintenance of vehicles, plant and equipment, in highway construction and maintenance, etc.) is more difficult to measure. Hirst and Herendeen (Ref. 42) suggest that indirect energy consumption by the car in the US may be as high as 60% of its total, and the same order of magnitude may be appropriate for other modes.

### DIRECT CONSUMPTION, BY PRIMARY SOURCE

Information published by the Petroleum Information Bureau (Ref. 57) and the Electricity Supply Association of Australia (Ref. 29) provides a breakdown of the sources of energy used in the transport sector. Measured in $10^{12}$ kJ units, of the total of 583 units, 515 are derived from petroleum products (3.0 from aviation gasoline, 276.6 from super motor spirit, 61.8 from standard motor spirit, 45.6 from aviation turbine fuel, 2.5 from power kerosene, 125.4 from automotive diesel distillate), and 2.4 from utility electricity. The balance of 66 units would appear to be derived directly from coal.

The overwhelming importance of petroleum as a transport fuel is clearly illustrated in the preceding figures. Over 88% of direct transport energy is derived from petroleum products. Motor spirits make up 66% of all petroleum products directly used in transport, automotive distillate 24%, and aviation fuels 9%.

The Australian figures may be compared with those for the US for the same year, recorded in Ref. 28: total direct consumption was $17920 \times 10^{12}$ kJ, of which $17024 \times 10^{12}$ kJ (95%) were derived from petroleum, $19 \times 10^{12}$ kJ (0.1%) from utility electricity, $7 \times 10^{12}$ kJ (0.04%) from coal, and $870 \times 10^{12}$ kJ (4.9%) from natural gas. It would be reasonable to conclude from these figures, in view of the relative growth in the use of petroleum-fueled transport modes, that petroleum might be expected to increase its share of the transport energy market in Australia, although relative changes in the cost of transport fuels would temper the extent to which it does so.

On a per capita basis, Australia consumes about $46 \times 10^{6}$ kJ per capita year (directly) in transport compared with a US figure of $86 \times 10^{12}$ per capita year (Ref. 41). The matter of a rising per capita consumption is considered further in Chapter 6 in the discussion of the implication of an increasing standard of mobility, identifying the effects of the increasing use of energy-intensive transport modes.

Kalma and Aston (Ref. 46) reported a more detailed analysis of energy directly consumed by transport in New South Wales in 1970-71. The total (direct) consumption of $181 \times 10^{12}$ kJ was made up in the manner set out in Table 4.1.

DIRECT ENERGY CONSUMPTION, BY MODE

It is somewhat surprising, in view of the current atmosphere of concern, that the published literature lacks a comparative analysis of the amounts of energy directly (let alone indirectly) consumed by the various categories of transport in Australia, although some credit must be given to the work of Kalma and Aston quoted above. Although there is no published breakdown of transport fuel sales for the purpose of, for example, rural road freight or urban rail passenger transport, the direct consumption by each category may be calculated from estimates of the traffic task performed by each and the average fuel consumption rates of the vehicles used.

TABLE 4.1 - DIRECT ENERGY CONSUMPTION BY TRANSPORT IN NSW, 1970-71

| Mode | Direct energy consumption (kJ x $10^{12}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Coal (direct) | Electricity | Aviation fuels | Motor spirit | Kerosene | Diesel distillate | Total | (%) |
| Railways | 3 | 1 | - | - | - | 8 | 12 | (6.3) |
| Aviation | - | - | 20 | - | - | - | 20 | (10.6) |
| Motor Vehicles | - | - | - | 119 | 1 | 37 | 157 | (83.1) |
| Total | 3 | 1 | 20 | 119 | 1 | 45 | 189 | (100.0) |
| (%) | (1.6) | (0.5) | (10.6) | (62.9) | (0.5) | (23.8) | | (100.0) |

Source: Kalma and Aston (Ref. 46)

In this literature review, it is not appropriate to include such an analysis, but the sources of the necessary information are described below. Before this is done, however, it is useful to indicate the results of a similar study undertaken recently in the US, which suggests a possible source of information where Australian statistics are inadequate and where US figures may serve as a useful proxy.

Ellis (Ref. 30) has calculated the breakdown by mode of total direct energy consumption in transport in the US. The result is summarised in Table 4.2, with figures representing the percentage used by each mode.

THE TRAFFIC TASK PERFORMED BY AUSTRALIAN TRANSPORT

Essential to an analysis of the consumption of energy by the various categories of transport, and the basis of the studies quoted above, is a breakdown of the traffic task performed by each. Despite the inadequacies of data relating to the output of the transport sector, sufficient exists to construct, albeit with acknowledged lack of precision, a table of consumption by Australian transport at least comparable to that above.

Australia's transport task may be said to comprise the significant categories shown in Table 4.3.

Data on the performance of each of these categories do exist in various published sources; either from the annual reports of operating or regulating authorities or from specific surveys and studies. The road transport task, for example, may be estimated from the results of the CBCS Survey of Motor Vehicle Usage, 1971 (Ref. 16) and from an examination of recent transport studies undertaken in the majority of urban areas during the last decade.

In most cases, and certainly for the more significant categories, the traffic task may be evaluated in terms of vehicle-kilometres, passenger-kilometres and tonne-kilometres.

TABLE 4.2 - ESTIMATES OF THE MODAL SHARES OF TOTAL ENERGY DIRECTLY CONSUMED BY TRANSPORT IN THE US, 1970

| Mode | Proportion of total (direct) transport energy consumption (%) |
|---|---|
| Cars | 53 |
| Trucks | 22 |
| Buses | - |
| Rail | 3 |
| Aircraft | 13 |
| Pipelines | - |
| Coastal Shipping | 4 |
| Other | 5 |
| Total | 100 |

Source: Ellis; Ref. 30.

TABLE 4.3 - SIGNIFICANT CATEGORIES OF AUSTRALIA'S TRANSPORT TASK

| Mode | Type | Location/trip length |
|---|---|---|
| Air | Passenger | International<br>Inter-urban |
| | Freight | International<br>Inter-urban |
| | Private | - |
| Sea | Passenger | International<br>Metropolitan (ferry) |
| | Freight | International<br>Coastal (= inter-urban) |
| Rail | Passenger | Metropolitan - journey-to-work<br>- other<br>Interstate<br>Inter-urban (intra-state) |
| | Freight | Metropolitan<br>Interstate<br>Inter-urban (intra-state) |
| Road | Bus Passenger | Metropolitan - journey-to-work<br>- other<br>Other urban centres<br>Interstate<br>Inter-urban (intra-state) |
| | Car Passenger | Metropolitan - journey-to-work<br>- business<br>- shopping<br>- social/recreational<br>Interstate<br>Inter-urban (intra-state) -<br>- business<br>- recreational |
| | Freight | Metropolitan<br>Interstate<br>Inter-urban (intra-state) |

## UNIT RATES OF ENERGY CONSUMPTION BY MODE

Whilst little convenient published information exists on the average rates of energy consumption by the various categories of vehicle in the Australian transport industry, the figures should not be difficult to find or derive.

The average amount of fuel consumed per vehicle kilometre may be deduced, in the cases of publicly owned services, from the published annual reports of the respective operating authorities. In particular, the consumption rates of air and rail services (urban, intra and interstate) may be found by correspondence with the Air Transport Group of the Department of Transport and the various State railway authorities. In the case of coastal and overseas shipping, the Department of Transport's own information is probably better than any published. For the road transport sector, the recently published results of the CBCS Survey of Motor Vehicle Usage, undertaken for the year ending September 1971, provide figures for the average rates of fuel consumption by type of vehicle and kind of fuel, which may be combined with the Census estimates of the road traffic task.

The amount of fuel consumed per kilometre in each case may, of course, be converted to units of energy by means of the known calorific value of each type of fuel.

The derived values, however, provide little indication of the efficiencies with which the various modes utilise input energy in performing their respective tasks. For this purpose, the term 'energy intensiveness' has been coined to denote the amount of energy consumed by each type of transport vehicle per passenger-kilometre or per tonne-kilometre. This term permits a comparison of modal energy efficiencies on a common basis.

Clark (Ref. 14) presents an analysis of the energy intensiveness of various Australian passenger transport modes under prevailing conditions of vehicle occupancy (see Table 4.4).

TABLE 4.4 - ENERGY INTENSIVENESS OF VARIOUS MODES OF AUSTRALIAN PASSENGER TRANSPORT

| Mode | Energy Intensiveness (kJ/pass-km) |
|---|---|
| Walking | 145 |
| Cycling | 85 - 105 |
| Tram | 1,250 |
| Bus | 1,340 |
| Train | 1,050 |
| Car | 3,770 |
| Air | 5,230 |

Source: Clark (Ref. 14).

It should be possible to derive, to a sufficient level of accuracy, the energy intensiveness of Australian modes of transport. An analysis of this kind would be worthwhile, for, as Mooz (Ref. 52) has suggested, the effect of fuel price changes may bear some relationship to the efficiencies with which each mode utilises energy in performing its total traffic task.

INDIRECT ENERGY CONSUMPTION BY TRANSPORT

The amount of energy consumed directly in propelling transport vehicles represents only a portion of the total energy consumed by the sector. The percentage will obviously vary from mode to mode, and very little indication is provided in the literature of the extent of the balance, with the exception of the case of cars. Even the few studies which have been reported are far from comprehensive and should be viewed simply as indicators of orders of magnitude.

In the only Australian study in this field, Beck (Ref. 5) estimates that the energy required to manufacture an average weight car in Australia is in the range $46 \times 10^6$ to $60 \times 10^6$ kJ which leads to an indirect consumption of about 190 to 250 kJ/passenger kilometre.

Studies of the energy consumed in the ancillary activities associated with car transport have been conducted in the US by Hannon (Ref. 38), Hirst (Ref. 41) and Hirst and Herendeen (Ref. 42). The results are shown in Table 4.5.

A comparison of these estimates and those of the direct energy consumption by cars suggests that indirect energy used by the transport industry forms a significant part of total energy used for transport. Hirst and Herendeen (Ref. 42) suggest that in the US in 1970 direct energy consumption by cars amounted to $9390 \times 10^{12}$ kJ (13% of the total US energy budget) while as much as $5800 \times 10^{12}$ kJ were consumed in petroleum refining, automobile manufacturing and sales, repairs, maintenance, parts and highway construction, that is, nearly 40% of the total transport usage.

Indirect energy consumption by the automotive and related industries is shown to be of considerable significance. There is, however, little to indicate whether this is so for other modes.

TABLE 4.5 - ESTIMATES OF INDIRECT ENERGY CONSUMPTION BY CARS THE US ($10^{12}$ kJ)

| | Hannon | Hirst | Hirst & Herendeen | |
|---|---|---|---|---|
| | (a) | (b) | (c) | (d) |
| Fuel - production | 6,181 | 8,397 | 5,907 | 9,430 |
| - refining | 1,287 | 1,730 | 1,350 | 2,184 |
| - retailing | 137 | | | |
| Oil - production | 53 | | 74 | 116 |
| - retailing | 21 | | | |
| Cars - production | 1,065 | 1,108 | 907 | 844 |
| - retailing | 369 | 1,044 | 170 | 222 |
| Tyres - production | 84 | | 95 | 243 |
| - retailing | 21 | | | |
| Maintenance and parts | 359 | | 369 | 390 |
| Parking - construction and maintenance | 411 | | 232 | 464 |
| Highway construction and maintenance | 612 | | | |
| Insurance | 295 | | 200 | 327 |
| Other | | 4,167 | 770 | 1,055 |
| Total | 10,895 | 16,446 | 10,074 | 15,275 |

(a) for 1963. (b) for 1968. (c) for 1960. (d) for 1970.

Sources: Hannon (Ref. 38); Hirst (Ref. 41); Hirst and Herendeen (Ref. 42).

## CHAPTER 5 REVIEW OF TECHNOLOGIES LIKELY TO AFFECT THE DEMAND FOR TRANSPORT ENERGY

The review of literature on technologies of both fuel supply and transport provided little information of direct assistance in determining likely changes in the patterns of transport fuel consumption in Australia in the future and the possible stages of evolution or substitution which may occur. For example, no likely revolutionary 'breakthrough' is apparent in the short to medium terms, but it is possible that changes in economic circumstances could change this situation. Certainly novel forms of transport technology or energy conversion have been mooted, but in almost every case the limited economic analyses which have so far been conducted into their feasibility suggests that they are not yet ready for introduction.

Australia, in particular, can be said to be in a somewhat fortunate position in respect to new technologies. In contrast with a number of other similarly industrialised countries, Australia can afford to draw on its own comparatively abundant resources whilst evaluating new technologies as proposed and implemented elsewhere.

Even overseas, however, surprisingly little definitive data has been published which might provide a measured indication of the likelihood of substitution and evolution effects of new technologies, both transport and fuel, within the transport sector. There is, though, some unanimity of opinion over the short term, during which it is considered likely that the bulk of the transport task will remain dependent on conventional fuels. Undoubtedly, changes may be foreseen, for example, as a result of emission control legislation in the case of conventional motor spirit, but the effects of these changes on the cost of fuel and the resulting redistribution of modal shares of the transport task have not been carefully analysed in the literature.

In the following discussion, it is evident that there is a concentration on issues concerning car transport. This is principally caused by a preponderance of literature on the subject, but is also a result of the consultants' decision to focus attention on the more significant aspects of the transport spectrum rather than attempt a time-consuming search for points of detail in areas with relatively minor impact on Australia's patterns of energy consumption.

Thus, in view of the importance of road transport, the majority of this section is devoted to a consideration of new technologies with likely relevance to the demand for transport by road vehicles, and the possible patterns of evolution of road transport fuel usage.

Specifically referring to automotive fuels, for example, Levine and Longosz (Ref. 49) suggest that future motor fuels will be in the form of higher octane unleaded petrols, as a result of restrictions on vehicle emissions, which will cost more to manufacture but will provide greater economy at the consumption stage (see Table 5.1).

Corner and Cunningham's figures, quoted in Levine and Longosz (Ref. 49), conflict with the findings of Ellis (Refs. 30 and 31), Bowden (Ref. 9), Hottel and Howard (Ref. 43) and the Petroleum Industry Environmental Conservation Executive (Ref. 56). The latter, in an argument for permitting the use of lead additives, has estimated that the projected legislation on lead additive levels in Australia would require expenditure of $A124 million on new refinery plant and would increase annual crude oil consumption by 13 million barrels. Importantly, Hottel and Howard (Ref. 43) point out that if lead content is reduced, then the aromatic content of the gasoline will have to be increased in order to retain present octane ratings, with a consequent necessity for emission control systems which would reduce fuel economy.

TABLE 5.1 - COMPARATIVE EFFECT OF OCTANE RATING ON UNLEADED PETROL FUEL PERFORMANCE

| Research Octane No. | Compres -sion ratio | Relative fuel con- sumption | Relative customer price (¢US/US gal) | Relative fuel cost (¢US/US gal) | Relative crude required |
|---|---|---|---|---|---|
| 91 | 6.8 | 100 | Base* | Base* | 100 |
| 97 | 8.3 | 89 | Base + 4 | Base + 2 | 89 |

* Base figures not given.

Source: Corner and Cunningham (Ref. 21), quoted in Levine and Longosz (Ref. 49).

It is obvious that the consequences of changing conventional fuel composition require more detailed study. In particular, the pollutive effects of lead additives and the possible harmful effects of the intake of lead by humans are matters which could be of considerable importance. It is beyond the scope of this report to attempt such an analysis.

For the longer term, consideration has been given in the literature to the feasibility (predominantly in a technological sense) of alternative power sources. Investigation has proceeded in two main directions:

(i) production of conventional fuels from alternative primary energy sources (as an example, the production of electricity using solar energy); and,

(ii) the use of synthetic fuels (for example, hydrogen).

CONVENTIONAL FUELS FROM ALTERNATIVE PRIMARY SOURCES

Considerable research has been undertaken recently into the question of the technological and economic feasibility of using alternative primary energy sources to generate electricity. The relevance of it all to the energy requirements of the transport sector in Australia, however, depends on the likelihood of introducing electric powered vehicles, the possibility of expanded use of electric public transport vehicles and the extent to which the use of electricity in other sectors could make available more fossil fuels for transport use.

Various methods of electricity generation have been postulated. The use of gravitation, winds, tides, and natural thermal and electrical gradients have been discussed in the literature, but have little possibilities of application in Australia in the immediate future. Nuclear and solar generation of electricity have, however, received more extensive attention. Nuclear energy already plays a significant role in some countries. The Institute of Fuel (Ref. 44) quotes a figure of 10% as the proportion of total fuel consumption provided by nuclear power stations in the United Kingdom at present and suggests that by 1985 15% of US energy needs will be met by nuclear energy.

An indication of the 1972 cost differential between thermal and nuclear generation is provided by De Bruin (Ref. 24):

| Thermal plant | Nuclear plant (light water reactor) |
|---|---|
| 1.92 ¢US/kWhr | 0.5 - 0.6 ¢US/kWhr |

Although nuclear plant running costs are lower than for an equivalent thermal power station, capital costs are considerably higher.

Likely trends in the unit cost differential are difficult to forecast. Carr (Ref. 12), however, suggests that the relative capital cost of nuclear plants may gradually reduce through economies of scale, and the Institute of Fuel (Ref. 44) predicts a rise in the cost of fossil fuels, which may further reduce the price differential. Whether or not the conclusions of the Institute of Fuel, based on British figures, are valid under Australian conditions, however, is a matter of some doubt.

Overseas trends in nuclear power technology are at present aimed at developing fast breeder reactors to the point of economic viability. A predicted shortage of uranium would support this development. In the literature, however, world uranium reserves are variously estimated as being 'well over 100,000 times the energy of the world's supply of fossil fuels' (Ref. 30) and '(insufficient to) last after 2000 AD' (Ref. 7). Australia, however, is undoubtedly comparatively well-endowed with reserves of uranium (see Table 2.4). Nevertheless, a gradual rise in the cost of uranium is probably inevitable as easily recoverable resources are exhausted, but this would have the effect of increasing economically recoverable reserves. The effect of price on US reserves, for example, is illustrated in the following figures from the US Atomic Energy Commission and quoted in Ref. 43:

| Price of uranium concentrates - \$US/kg | US reserves of uranium (at this or lower price) - tonnes |
|---|---|
| 18 | 604,000 |
| 22 | 955,000 |
| 33 | 1,473,000 |
| 66 | 2,276,000 |
| 110 | 10,160,000 |
| 220 | 25,401,000 |

The development of the fast breeder reactor is seen as effectively increasing US uranium reserves by a factor of 130 and making the cost of electricity almost independent of uranium costs. Just what effect the breeder reactor will have on the actual price of electricity in Australia is not defined. Certainly, the initial capital investment on plant is greater for the fast breeder reactor than for the conventional nuclear power stations (light water reactor). Hottel and Howard (Ref. 43) quote a figure of US$255 per kW versus US$175 per kW for a light water reactor for 1985, but these estimates are sensitive to changes in the cost of uranium fuel.

The economic viability of nuclear power generation in Australia is not clear. Its use is predicted by Carr (Ref. 13) by the 1980's but Gleeson (Ref. 37) suggests it will not be warranted until the next century.

One other electrical generation alternative receiving serious attention is solar energy. The literature would seem to indicate that the concept of massive tracts of land devoted solely to the collection of solar energy is illusory. Hottel and Howard (Ref. 43) indicate that devices to intercept or collect solar energy benefit little by scale increase. Consequently, if solar energy is to find extensive use it will tend to be in small units to accomplish individually small tasks. Areas of possible application would be water and air heating, air conditioning and in some cases water desalination. Significant work in this direction has been carried out by the CSIRO (Ref. 53) and the University of Queensland (Ref. 62).

The amount of portable fossil fuel which may be released by the widespread use of electricity generated from non-fossil fuels requires closer examination, for it has implications for the transport sector. A preliminary estimate for the US is provided by Day (Ref. 23). He estimates that it may be feasible to substitute nuclear fuels for up to 45% of fossil fuel consumption.

A particularly relevant area of interest in the search for alternative primary energy sources is the possibility of extracting gas from coal, or oil from coal, oil shale and tar sands. Hottel and Howard (Ref. 43) suggest that since these resources are so enormous they will inevitably become economic to tap. A comparative analysis of the costs of energy from these sources is presented in Table 5.2. The analysis was performed for US conditions, however, and may have little direct relevance to the present Australian context. The same may be said of an analysis by Williams and Van Lookeren Campagne (Ref. 65), the findings of which are presented in Table 5.3.

At the present time, the extraction of oil from oil shale and tar sands appears to be marginally viable in North America. Extraction from brown and black coal may hold more potential for Australia in the longer term due to abundant reserves of each, but more research is necessary before the economic feasibility can be established.

SYNTHETIC FUELS

The literature suggests fairly strongly that over the long term (the scale of which is not at all clear) the use of synthetic fuels from non-fossil sources will inevitably become necessary. Obviously, the feasibility of substituting such fuels for conventional power sources depends on the economics of production and the extent to which such substitution is technically possible. Principal among the contenders for the transport energy market are synthetic gasoline, methane, methanol, ethanol, hydrogen ammonia and hydrazine. A comparison published in SAE (Ref. 63), is presented in Table 5.4 and selected cost figures are shown in Table 5.5.

TABLE 5.2 - ESTIMATES OF THE COST OF UTILISING NEW PRIMARY ENERGY SOURCES, US

| Primary energy (source) | Secondary energy (product) | Primary energy cost per tonne | Secondary energy cost | Cost of energy equivalent of oil | DCF rate of return % |
|---|---|---|---|---|---|
| Coal | Gas | \$4.11 | 52-64c/ $10^6$ kJ | \$20 06- \$24.84/kl | |
| Lignite | Gas | \$2.01 | 45c/ $10^6$ kJ | \$17.11/kl | |
| Coal (Consol process)[a] | Oil | \$1.12 | \$20.44/ kl | - | |
| Coal (H-coal process)[a] | Oil | \$2.90 | \$23.77/kl | - | 10 |
| Coal (COED process)[a] | Oil | \$2.68 | \$25.16/ kl | - | 10-16 |
| Tar sands | Oil | - | \$22.64/ kl | - | 5.8 |
| Oil shale | Oil | - | \$22.64/ kl | - | 9.9 |

(a) For details of the processes, see Ref. 43, Chapter 3.

Source: Hottel and Howard (Ref. 43).

TABLE 5.3 - COMPARISON OF ALTERNATIVE SOURCES OF PRIMARY ENERGY, US (1970 prices)

| Primary energy | System | | | Product | |
|---|---|---|---|---|---|
| | Conversion route | Thermal efficiency (%) | Capital costs ($US/tonne /yr) | Type | Exchange cost ($US/kJ x $10^6$) |
| Crude oil | Refining | 94 | 20-30 | Petrol | 90 |
| Coal, shale, tar sands | Gasification | 65-75 | 50-75 | Synthetic natural gas | 70-100 |
| | Syncrude | 65-75 | 60-100 | Petrol | 70-120 |
| Nuclear | Water/ $CaCO_3$ | 34 | 220 | Methanol | 450 |
| | Fischer-Tropsch | 34 | 220 | Petrol | 450 |

Note: For an explanation of the conversion processes, see Ref. 43.

Source: Williams and Van Lookeren Campagne (Ref. 65).

TABLE 5.4 - COMPARISON OF SYNTHETIC PORTABLE FUELS

| Fuel | Density ($kg/m^3$) | Energy density ($J/kg$) x $10^3$ | Energy density ($J/m^3$) x $10^5$ | Amount equivalent to 20 US gal petrol: litres | Amount equivalent to 20 US gal petrol: kg(fuel) | Amount equivalent to 20 US gal petrol: kg(fuel and storage tank) |
|---|---|---|---|---|---|---|
| Typical petrol | 702 | 44,380 | 311,700 | 75.7 | 53.1 | 68 |
| Methane gas | 114 | 50,000 | 56,850 | 415 | 47.2 | 500 |
| Liquid propane | 510 | 44,400 | 236,000 | 100 | 51.1 | 85 |
| Methanol | 797 | 20,100 | 160,200 | 147 | 117 | 141 |
| Ethanol | 795 | 26,860 | 213,700 | 110 | 88.0 | 107 |
| Liquid hydrogen | 71 | 120,900 | 85,900 | 275 | 19.5 | 136 |
| Hydrogen gas | 1.07 | 120,900 | 12,924 | 1,820 | 19.5 | 2,090 |
| Metal hydride | 1,760 | 10,100 | 179,000 | 132 | 233 | 284 |
| Liquid ammonia | 771 | 18,600 | 143,500 | 164 | 127 | 152 |

Source: SAE (Ref. 63).

TABLE 5.5 - SELECTED COSTS OF SYNTHETIC FUELS IN THE US

| Fuel | Cost/litre (¢US) | Cost/$10^6$ kJ ($US) |
|---|---|---|
| Synthetic methanol | 3.2 | 1.99 |
| Gasoline at the refinery | 3.7 | 1.25 |
| Ethanol | 14.3 | 6.92 |
| Hydrogen, derived: | | |
| (a) electrolytically | 7.4 | 2.84 |
| (b) from coal | 2.4 | 0.95 |

Source: SAE (Ref. 63).

Savery (Ref. 61) provides some additional information in Table 5.6.

Day (Ref. 23) attempts to estimate the changes in the price differential between selected natural and synthetic fuels in the future (see Table 5.7).

It is obvious that overseas published estimates differ considerably. Until more research is undertaken locally, the use of estimates of the feasibility of the new fuel sources from the US and elsewhere is of limited value in assessing the likelihood of fuel substitutes in Australia.

NEW SOURCES OF ENERGY FOR TRANSPORT

The preceding discussion does not directly address the specific fuel requirements of the transport sector. The choice of likely transport fuel alternatives, whilst obviously dependent on the overall technological and economic viability of new fuel sources, is also influenced by the extent to which the fuels may be used in the more demanding and limited area of vehicle propulsion. In other words, transport hardware must be capable of utilising efficiently such fuels. Such data as exist on the question of the transport technology-fuel interface is far from comprehensive and necessarily somewhat subjective. The prospects of some of the fuels which could be used in road transport are discussed in Ref. 63. Table 5.8 summarises the discussion.

Williams and Van Lookeren Campagne (Ref. 65) have attempted a limited comparison of a number of possible motive plants and their energy conversion efficiencies. The results are shown in Table 5.9.

Very little information is available on the use of synthetic fuels for transport modes other than road vehicles. Boorer (Ref. 8), however, discusses their use as aviation fuel, his arguments centering on the restrictive weight and volume requirements of aircraft propellants. Figure 5.1 summarises his conclusions.

TABLE 5.6 - CHARACTERISTICS OF SYNTHETIC FUELS

| Fuel | Heating value (kJ/kg) | Octane rating | Relative specific fuel consumption ($10^{-3}$ $m^3$/kWh) |
|---|---|---|---|
| Petrol | 50,233 | 100 | 38.0 |
| Methane | 55,581 | 140 | 269.6 |
| Alcohol | 34,651 | 107 | 41.8 |
| Hydrogen | 143,023 | (low) | 83.5 |
| Ammonia | 22,512 | 100 | 94.9 |

Source: Savery (Ref. 61).

TABLE 5.7 - FORECAST PRICE CHANGES FOR SELECTED NATURAL AND SYNTHETIC FUELS (UK)

| Fuel | Fuel price UK pence/thousand MJ | |
| --- | --- | --- |
| | Year 1971 | Year 2000 |
| Run of mine coal | 21.8 | 38.9 - 43.6 |
| Crude oil | 19.9 | 61.6 - 71.1 |
| Natural gas | 31.3 | 71.1 - 75.8 |
| Hydrogen (gas) | 37.9 - 42.7 | 151.7 - 170.6 |
| Hydrogen (liquid) | 151.7 | 246.4 - 265.4 |
| Petrol | 42.7 | 104.3 - 113.7 |
| Methanol (from limestone) | - | 255.9 - 312.8 |

Source: Day (Ref. 23).

TABLE 5.8 - PROBLEMS AND PROSPECTS FOR THE USE OF SYNTHETIC PORTABLE FUELS IN TRANSPORT

| Fuel | Problems | Prospects |
|---|---|---|
| Propane | Must be stored under moderate pressure | Limited |
| Ammonia | Must be stored under moderate pressure | Limited |
| Hydrazine | Toxic and dangerous to handle | Limited |
| Hydrogen | Must be stored under high pressure | Long-term pressure |
| Methanol | (a) | Quite good in short-term |
| Ethanol | (a) | Quite good in short-term |
| Methane | Stored under high pressure | Limited |

(a) The reference is not specific on the question of developmental costs and long-run fuel costs. Thus, the 'quite good' prospects of methanol and ethanol may be based only on a consideration of the types of physical problems suggested for the other fuels.

Source: Derived from SAE (Ref. 63).

TABLE 5.9 - COMPARISON OF SELECTED FUEL SYSTEMS

| Fuel | Conversion efficiency (%) | | | Investment ($US/kW) | |
|---|---|---|---|---|---|
| | Process plant | Power plant | Overall | Plant | Plant and nuclear plants[d] |
| Synthetic methanol | 34 | 50[a] | 17 | 675 | 2,175 |
| Synthetic petrol | 34 | 15[b] | 5 | 2,660 | 7,660 |
| High energy battery | 50 | 90[c] | 45 | 2,950 | 4,150 |

(a) Fuel cell and electric motor.

(b) Petrol engine.

(c) Electric motor.

(d) Total capital cost of conversion plant and nuclear plant where nuclear generated electricity is used to power the conversion processes. Nuclear plant costs are assumed to be US$300/kW.

Source: Williams and Van Lookeren Campagne (Ref. 65).

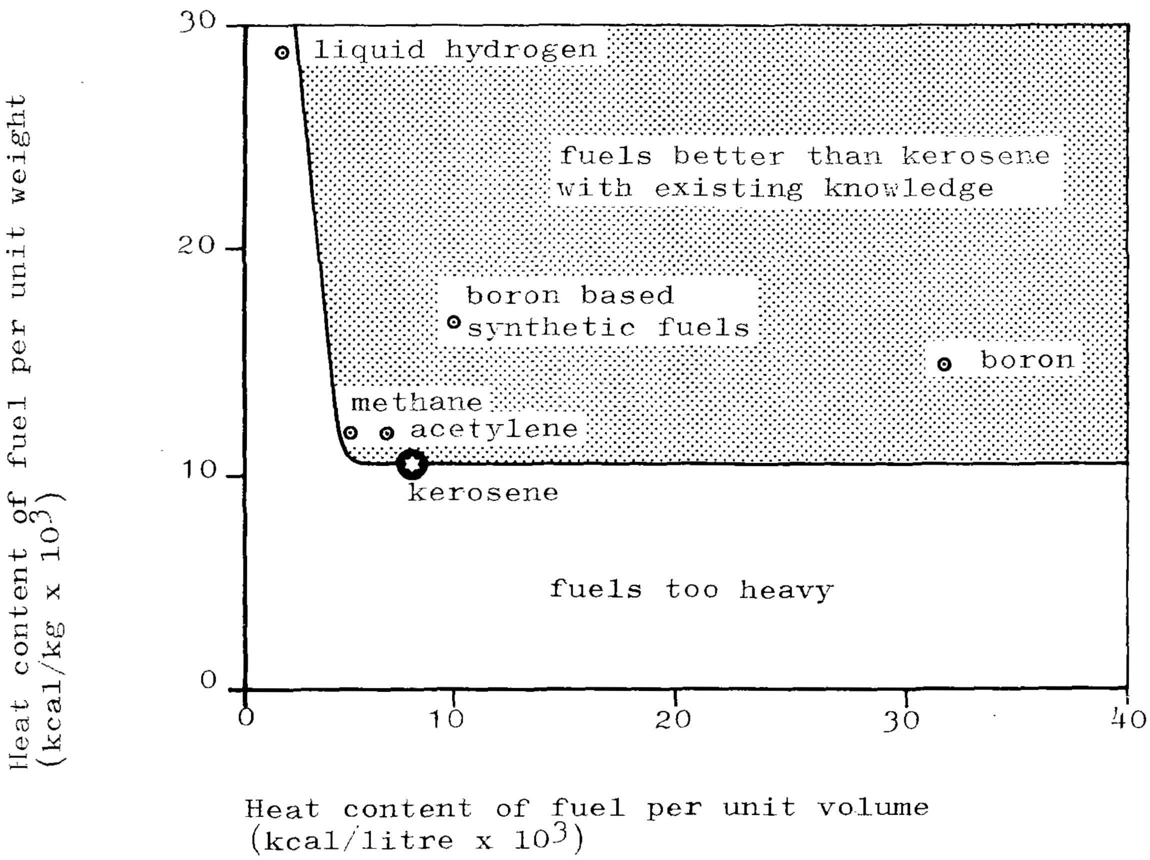



FIGURE 5.1 - COMPARISON OF POTENTIAL AIRCRAFT FUELS

Source: Boorer (Ref. 8)

MOTOR VEHICLE TECHNOLOGY

Very little has been published on short-term innovations in the technologies of transport modes other than the motor vehicle. The following discussion, therefore, is predominantly oriented towards the car, the principal subject of research and published literature, although many of the conclusions can be extended to apply to road vehicles generally.

Despite the attention given to the car, however, only a limited number of studies have identified the likely specific effects of recent developments in fuel supply and changes in government legislation controlling vehicle emission standards. These two developments are seen by most researchers to comprise the more influential of pressures likely to bring about changes in the pattern of evolution of road vehicles.

## Vehicle Design

In recent years, both in Australia and in the US, the average fuel consumption rate for cars has tended to increase, primarily because of increases in the overall weight of vehicles. Illustrative data on performance losses in the US are shown in Table 5.10.

In the same reference, the contribution of car components and accessories to the declining trend in fuel economy is examined. In a comparison of the relative fuel economies of a typical US subcompact car with manual transmission, and a typical luxury car with a 40% greater frontal area and automatic transmission, it is shown that the size and weight differences account for 80% to 90% of the variation in fuel consumption between the two. Other effects are shown on the following page.

| Component | Contribution to the difference in fuel economy: Under urban driving conditions % | Contribution to the difference in fuel economy: Cruising at 112 km/h % |
|---|---|---|
| Size and weight | 80 | 90 |
| Transmission | 15 | 5 |
| Accessories | 5 | 5 |

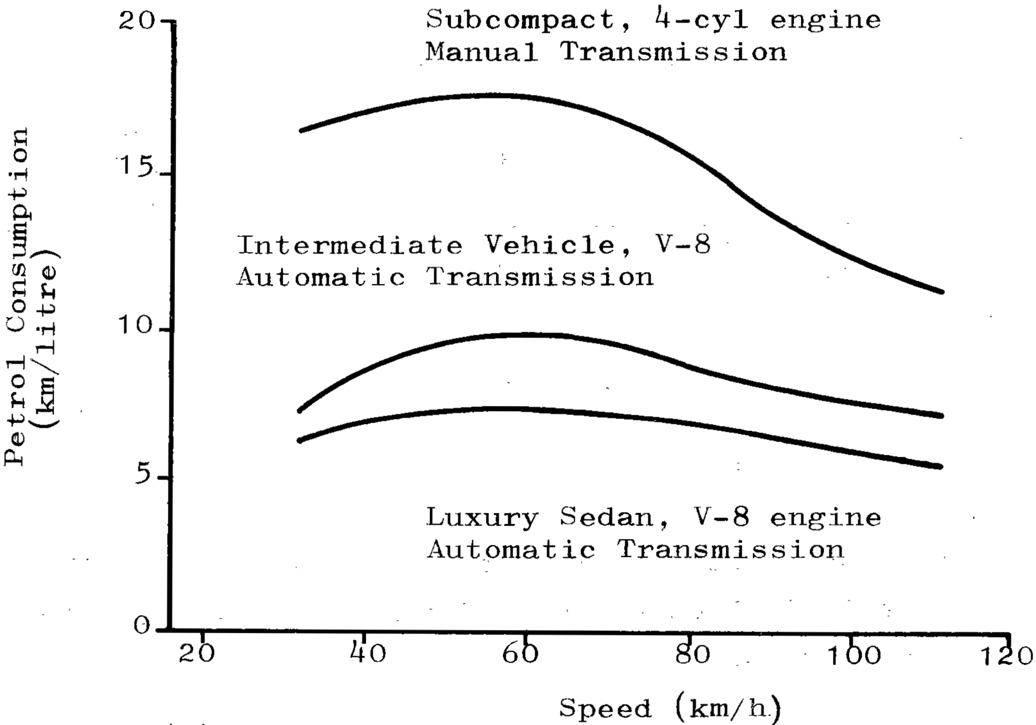
Source: SAE (Ref. 63)

The effects of four basic accessories on the fuel economy of a typical US V8-engined car with automatic transmission are shown below:

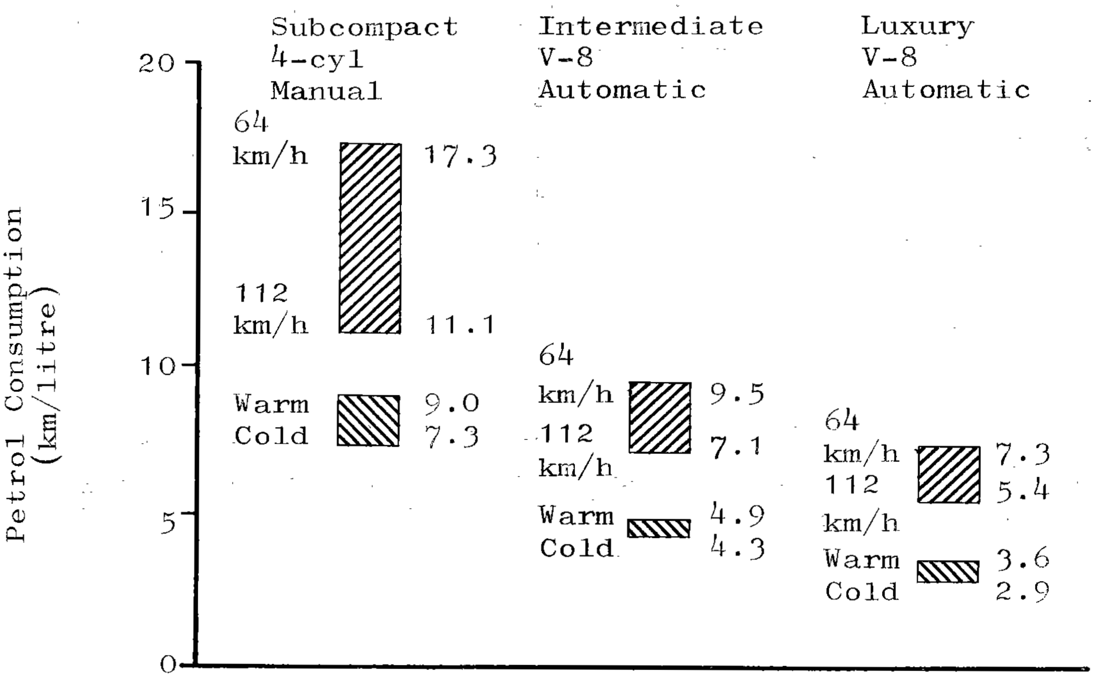
| Accessory | Increase in fuel consumption (expressed as decrease in km/litre): Under urban driving conditions (basic consumption: 4.9 km/litre) | Increase in fuel consumption (expressed as decrease in km/litre): Cruising at 112 km/h (basic consumption: 7.1 km/litre) |
|---|---|---|
| Air conditioning | 0.64 | 0.43 |
| Alternator | 0.38 | 0.21 |
| Fan | 0.43 | 0.21 |
| Power steering | 0.43 | 0.17 |

Source: SAE (Ref. 63).

The variation in fuel consumption with speed and under different running conditions for typical US cars is shown in Figure 5.2.




(a) Steady state operation on a level road




(b) Typical operating conditions :

urban and rural driving cycles

FIGURE 5.2 - VARIATIONS IN PETROL CONSUMPTION RATES OF TYPICAL U S VEHICLES

Source : SAE (Ref 63)

TABLE 5.10 - TRENDS IN PERFORMANCE AND FUEL ECONOMY FOR CARS IN THE US

| | Acceleration time (secs) | | Fuel economy (km/litre) | |
|---|---|---|---|---|
| | 0-96 km/h through gears | 80-112 km/h direct | Urban | 112 km/h |
| 1968 | 11.2 | 8.2 | 5.3 | 7.2 |
| 1973 | 12.6 | 9.5 | 4.3 | 6.8 |
| 1968-73 losses | 13% | 16% | 23% | 6% |

Source: SAE (Ref. 63).

It is unlikely that the trend towards larger and less economical cars will continue under recent conditions of rising fuel prices. In the US, sales of larger vehicles have declined drastically in favour of smaller imported models and locally produced 'compacts'. The same trends towards improved fuel economy are likely in Australia, albeit less dramatically influenced by fuel prices.

## Power plant technology

In recent years, largely in response to exhaust emission legislation, alternatives to the normal Otto cycle petrol engine have been under active consideration. To date, fuel economy has been a secondary consideration, although recent events might be expected to alter research priorities.

As Ayres and McKenna (Ref. 3) point out, an unfortunate characteristic of the internal combustion engine in its present form is its relative complexity and the maintenance problems which result. In addition, its level of pollutant emissions and, more recently, its consumption of petroleum fuel have been criticised.

It would appear that for an engine to be considered as a viable alternative to the conventional internal combustion engine, it must satisfy three conditions:

(i) meet the requirements of emission control legislation;

(ii) be economical in terms of fuel consumption; and,

(iii) not represent too dramatic a departure from present technology (as the developmental costs might prove prohibitive).

From a technical standpoint, the ideal engine should be self-starting and should produce maximum torque at zero speed, with torque dropping to zero at the maximum speed at which the engine will turn. The engine should require only a minimum of power-consuming auxiliaries (fan, water pump, transmission, etc.) and should achieve very nearly the same specific fuel consumption or conversion efficiency under conditions of low speed and heavy load as it does at high speed and no load. Finally, it should produce smooth, vibrationless power in the form of rotary motion, preferably transmitted directly to the wheels (Ref. 3).

A change in automotive propulsion technology would be accompanied, inter alia, by changes in cost (initial cost and maintenance), operation complexity and performance. The wider issues arising from a significant shift in car propulsion technology, however, cannot be fully discussed here. These include considerations of, for example, labour utilisation within the economy, the need for developing technical support and service industries associated with new processes of vehicle manufacture, the reorganisation of sales and maintenance infra-structures, and political and union pressures.

A number of sources have, however, undertaken performance and cost comparisons of alternatives to the conventional Otto cycle engine (see, for example, Refs. 3, 33, 40, 43, 61, 63 and 65). Ayres and McKenna (Ref. 3), in particular, present a detailed and comprehensive examination of possible automotive power plants, only a summary of which may be provided here. They also make a point worth noting in relation to the likelihood of technology substitution: since one can only rate power plants with respect to any given figure of merit if all other factors are equal, it is extraordinarily difficult to compare the various systems because they differ in very fundamental ways. In other words, the technology which best satisfied emission control legislation or fuel economy may well not be that which satisfies many other equally important requirements.

Thus, the variations in fuel consumption and energy consumption with average driving speed for various engines depicted in Figure 5.3 may be taken to have the correct qualitative behaviour but are based on somewhat arbitrary assumptions with regard to engine and vehicle characteristics.

A better basis for comparison is provided by Table 5.11, which shows a number of other performance characteristics, including energy efficiencies, for various power plant types, normalised to 74.5 kw (100 hp) at the rear wheels, although even in this case problems arise (present battery-electric systems, for example, cannot realistically provide 74.6 kw at the wheels in a practical-sized vehicle).

Savery (Ref. 61) also presents a comparison of alternatives to the conventional spark ignition, internal combustion engine and singles out the stratified charge engine, which shares features of both the conventional spark ignition and diesel engines. It offers a significant reduction in uncontrolled emissions and a 30% saving in fuel consumption, and does not represent a radical departure from conventional technology. Savery's results are shown in Table 5.12.

A further comparison of fuel consumption rates and vehicle weights of comparable cars powered by alternative power plants is made in Ref. 63. Figure 5.4 shows the results, and also indicates the way in which the average fuel consumption of conventional vehicles in the US has declined in recent years.

TABLE 5.11 - COMPARISON OF ALTERNATIVE POWER SYSTEMS PROVIDING A MAXIMUM OF 74.6 kW AT WHEELS OF MOTOR VEHICLE

| Engine | Transmission | Short term overload capacity (kW) | (a) Estimated parasitic losses % | (b) Power required to supply 74.6 kW wheels (kW) | Maximum brake thermal efficiency at normal full load % | Maximum energy conversion efficiency % | Total weight of power train (kg) |
|---|---|---|---|---|---|---|---|
| Otto-cycle, reciprocating (4-stroke) | 3-speed auto., or manual and clutch | 0 | 33 | 112 | 27-30 | 19 | 340 |
| Diesel, reciprocating | Same as Otto | 0 | 33 | 112 | 30-33 | 21 | 408 |
| with super-charger | | 22 | 35 | 86 | 28-30 | 19 | 340 |
| Differential regenerative gas turbine | Speed reducer differential | 19 | 25 | 82 | 20-26 | 17 | 181 |
| Steam Ranking (partial venting) | Differential | 19 | 28 | 82 | 18-24 | 14 | 324 |
| Thiophene (CP-34) Rankine | 2-speed, clutch, differential | Not specified | 28 | 101 | 17 | 13 | 499 |
| Future organic Rankine | As above | n.a. | 28 | 97 | 25 | 19 | 363 |
| Electric 10 kW (present) 30 kW (future) | Traction motors, speed reducer | n.a. | n.a. | n.a. | 30-39 (power station) | 0.63 kwh/km 0.31 kwh/km | 680 363 |
| Hybrid 60 kW max. (present) | Speed increaser electric generator, traction motors, speed reducer | 149 | 42 | 30 (balance supplied by batteries) | 30 | 17 | 578 |
| Stirling (closed cycle) | 2-speed and clutch | 37 | 40 | 82 | 32-38 | 22 | 499 |

NOTES: (a) Important parasitic losses which have been excluded are owner's options, such as power steering, power brakes, and air conditioner. (b) Overload power, where available, has been taken into account in calculating power requirement.

Source: Ayres and McKenna (Ref. 3)

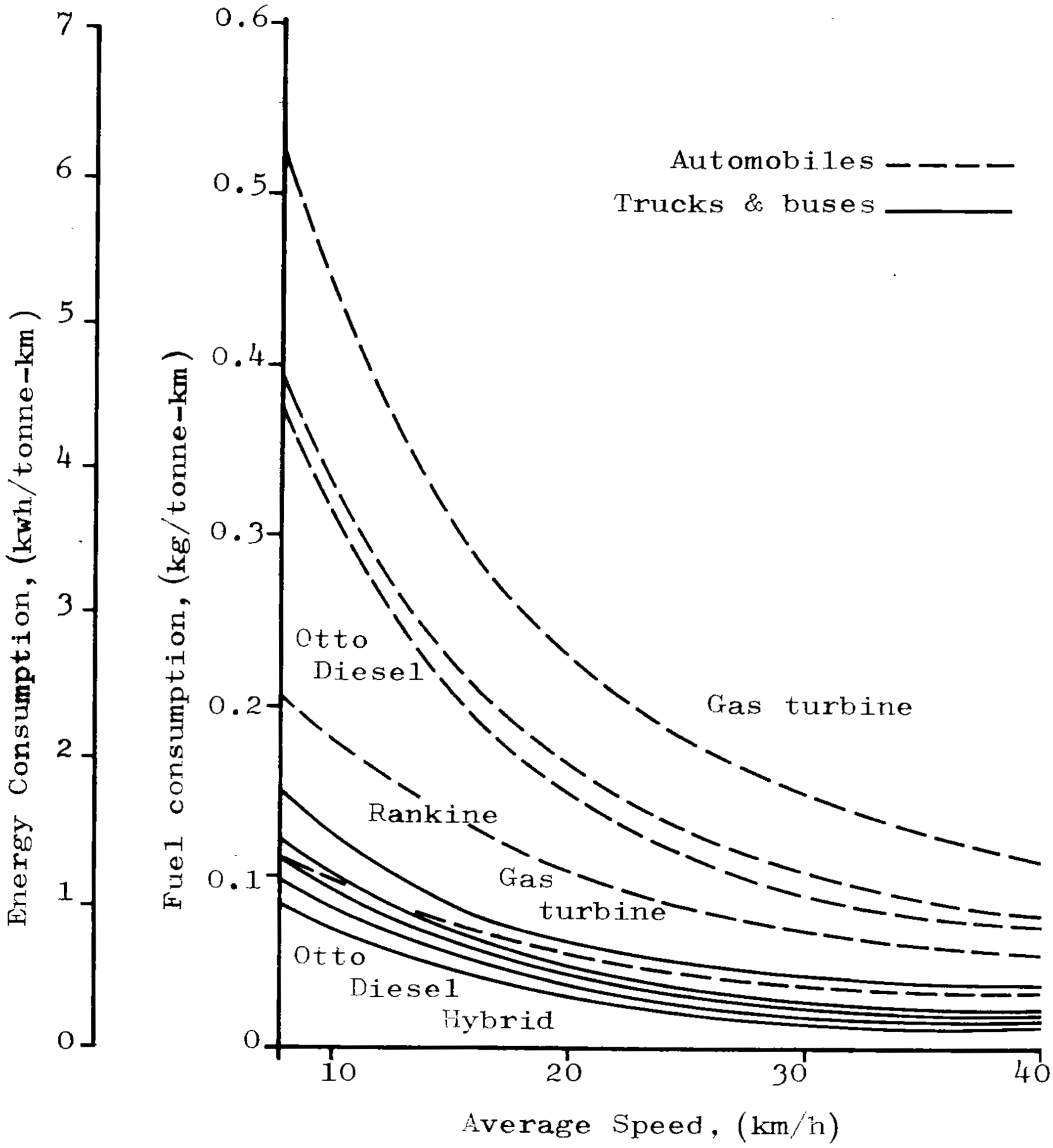



FIGURE 5.3 - ENERGY AND FUEL CONSUMPTION FOR VARIOUS ENGINES

Source: Ayres and McKenna (Ref. 3)

TABLE 5.12 - COMPARISON OF ALTERNATIVES TO THE CONVENTIONAL INTERNAL COMBUSTION ENGINE

| Engine Type | Specific Wt. (kg/kW) | Specific Fuel (kg/kWh) | Specific Cost (US/kW) | Emissions (% Conventional) | Comments |
|---|---|---|---|---|---|
| Conventional spark ignition | 2.4 | 0.27 | 5.4 | 100 | Highly developed |
| Rotary combustion (Wankel) | 1.2 | 0.30 | 5.4 | 120 | Developed and operating; potential cost savings; emissions problem |
| Stratified charge | 3.0 | 0.21 | 6.7 | 25 | Possible odour problem; has multifuel capability |
| Gas turbine (regenerative) | 1.8 | 0.27 | 8.0 | 20 | Noise problem; cost not proven; has multifuel capability |
| Diesel | 3.6 | 0.21 | 8.0 | 20 | Noise and odour problem; has multifuel capability |
| Stirling | 6.1 | 0.27 | 16.1 | 5 | Heavy and costly; has multifuel capability |
| Steam engine | 3.6 | 0.30 | 10.7 | 5 | Performance limitation; cost not proven; has multifuel capability |

Source: Savery (Ref. 61).

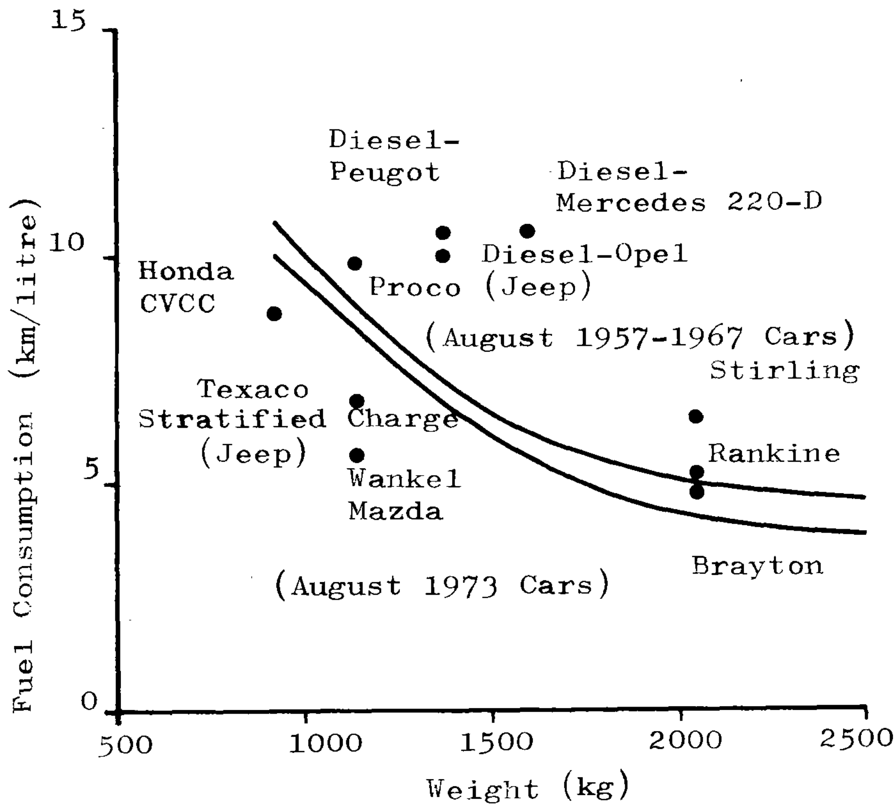



FIGURE 5.4 - COMPARISON OF FUEL CONSUMPTION RATES AND WEIGHTS OF CONVENTIONAL CARS AND SELECTED ALTERNATIVES, US

Source: Ayres and McKenna (Ref. 3)

Prompted by the rapidly increasing demand for petroleum fuels, there is a growing recognition of the need to develop power systems which may be adapted to changes in fuel technology (or more importantly, changes in the relative prices of fuels). Multifuel capability could become an important criterion for long-term investment planning. Few sources, however, address this problem. Fraize (Ref. 33) mentions the importance of this in a somewhat subjective way and notes that internal combustion engines are relatively limited in the range of fuels which they may utilise.

Williams and Van Lookeren Campagne (Ref. 65) have examined the question of the energy conversion efficiencies of alternative fuel technologies and their transport applications. Their conclusions are shown above in Table 5.9. These figures suggest that electric power for cars offers considerably reduced conversion losses, although the anticipated capital costs are higher than for petrol engines. Notwithstanding these costs, the expressed opinion of many authors is that the electric vehicle will ultimately supersede the hydrocarbon-fuelled vehicle. Predictions of this sort are often made under assumptions of improved battery technology or recharging facilities. Campbell (Ref. 11), for example, sees the possible widespread use of nuclear power in the US reducing the cost of electric vehicles to a competitive level.

Two types of electric vehicle have been examined: the all-electric battery powered vehicle and the heat engine/electric hybrid. Although the fuel cell has received some attention, its cost would seem to prohibit its use for cars (Refs. 3 and 43). The hybrid vehicle derives power from the engine under cruising conditions, but when additional power is needed, it is drawn from the battery. It has been suggested that in urban areas the vehicle could operate on battery alone to reduce emissions. The most important problem with hybrid vehicles lies in the inherent complexity of two separate power systems.

Another constraint on the feasibility of both hybrid and fully electric (non-hybrid) vehicles is the low specific energy of present day batteries. Hottel and Howard (Ref. 43), using information from Heitbrink and Tricklebank (Ref. 40), have postulated the energy requirements of various vehicles and have outlined the characteristics of various battery systems which could be used in such vehicles (see Table 5.13).

The most detailed comparison of the likely costs of alternative engines, including electric systems, is given by Ayres and McKenna (Ref. 3). Detailed though it is, the authors are careful to point out the dearth of accurate cost data based on careful well-documented engineering studies, and that most of the published cost estimates are not suitable for comparing different systems because of the bases from which they are derived.

Ayres and McKenna's estimates of first cost (i.e., basic cost of power plant), ten-year fuel costs and ten-year maintenance costs for alternative power systems are shown in Tables 5.14, 5.15 and 5.16, together with some of the assumptions on which they are based. These data are combined in Table 5.17, which shows the estimated ten-year net cost differences from the conventional internal combustion engine (based on 1970 system characteristics and fuel and material prices in the US). These show that over a ten-year period, only the diesel and a future (projected) organic Rankine-cycle engine offer cost saving over a 1970 model internal combustion engine. Consideration of differences from the 1975 ICE, however, indicate that in addition to these two types of engine, the steam and Stirling engines and electric drive (in particular) show promise.

Barbiroli (Ref. 4) presents the only published analysis of the possible impact of the introduction of a new passenger vehicle technology on national patterns of transport fuel consumption (in this case, the possible effects of introducing electric vehicles to Italy). Barbiroli's assumptions are not clear, but Table 5.18 shows his forecasts of crude oil savings resulting from an increase in the number of electric cars in Italy from 950,000 (5% of all cars registered) in 1980 to 7,800,000 (30% of all cars registered) by the year 2000.

TABLE 5.13 - APPLICATIONS AND CHARACTERISTICS OF BATTERIES FOR AUTOMOTIVE POWER

Operating characteristics of battery-powered vehicles

| Type of vehicle | Under constant speed | | | | Under acceleration |
|---|---|---|---|---|---|
| | Range (km) | Speed (km/h) | Energy density (Whr/kg) | Power density (W/kg) | Power density |
| Urban car | 81 | 64 | 55 | 44 | 143 |
| Commuter car | 161 | 97 | 121 | 73 | 154-227 |
| Family car | 322 | 113 | 269 | 95 | 161-243 |
| Metro truck | 161 | 64 | 73 | 29 | 88 |
| Urban coach | 201 | 48 | 93 | 24 | 77 |

Conventional ambient-temperature battery characteristics

| Battery | Open cell voltage | Theoretical energy density (Whr/kg) | Practical[a] energy density (Whr/kg) | Practical[a] power density (Whr/kg) |
|---|---|---|---|---|
| Lead-Acid | 2.1 | 176 | 4-33 | 33-176 |
| Nickel-Zinc | 1.7 | 375 | 33-55 | 66-220 |
| Zinc-Air | 1.6 | 1,058 | 88-165 | 44-77 |

(a) Representative values.

Advanced high-temperature battery characteristics

| Battery | Temp. | Open cell voltage | Theoretical energy density (Whr/kg) | Projected[b] energy density (Whr/kg) | Projected[b] power density (W/kg) |
|---|---|---|---|---|---|
| Lithium-Chlorine | 650 | 3.5 | 2205 | 331-441 | 198-397 |
| Lithium-Sulphur | 350 | 2.3 | 2690 | 243-353 | 551-794 |
| Sodium-Sulphur | 300 | 2.1 | 794 | 176-331 | 198-353 |

(b) These values are estimates based on equivalent battery packages. The ranges are not interrelated, but they indicate the current uncertainties in the design of these advanced battery systems.

Source: Heitbrink and Tricklebank (Ref. 40) quoted in Hottel and Howard (Ref. 43).

TABLE 5.14 - ESTIMATED FIRST COST OF ALTERNATIVE POWER SYSTEMS, US

| Power system | Rated power[(b)] (kw) | System weight[(c)] (kg) | Estimated first cost ($US) | Incremental cost over standard ICE ($US) |
|---|---|---|---|---|
| ICE[(a)] (spark ignition) | 112 | 341 | 750 | 0 |
| Diesel | 112 | 409 | 990 | 240 |
| Gas turbine (regenerative) | 82 | 200 | 1,500 | 750 |
| Ranking cycle[(d)] (steam) | 82 | 325 | 1,000 | 250 |
| Ranking cycle[(e)] (organic fluid) | 101 | 500 | 1,160 | 410 |
| Rankine cycle[(e)] (organic fluid, future) | 97 | 364 | 925 | 175 |
| Stirling cycle | 82 | 500 | 1,990 | 1,240 |
| Battery electric[(f)] (present) | 10 | 682 | 1,760 | 1,010 |
| Battery electric[(g)] (future) | 30 | 364 | 1,620 | 870 |
| Hybrid (ICE-electric) | 30-60[(h)] | 580 | 1,620 | 870 |

(a) ICE = Internal Combustion Engine.

(b) Except for electric and hybrid, to give 74.6 kW at wheels.

(c) Including transmission, if any.

(d) Incomplete condensing.

(e) Complete condensing.

(f) Lead-acid battery.

(g) Possible future battery, such as sodium-sulphur.

(h) 30 kW continuously from ICE, up to 60 kW for very short periods with assistance from battery.

NOTE: Cost estimates are based on product weights, with adjustments for likely reductions due to economies of scale.

Source: Ayres and McKenna (Ref. 3).

TABLE 5.15 - ESTIMATED TEN-YEAR FUEL OR ENERGY COSTS FOR ALTERNATIVE POWER SYSTEMS, US

| Power system | Fuel consumption (km/litre) | Total fuel cost[b] ($US) | Electrical energy cost[c] ($US) | Battery replacement cost ($US) | Estimated total energy cost ($US) | Cost difference, from standard ICE ($US) |
|---|---|---|---|---|---|---|
| ICE[a] (spark-ignition) | 5.5[d] | 2,560 | - | - | 2,560 | 0 |
| Diesel | 6.8 | 2,080 | - | | 2,080 | - 480 |
| Gas turbine (regenerative) | 4.3 | 3,320 | - | - | 3,320 | + 760 |
| Rankine (steam) | 5.1 | 2,770 | - | - | 2,770 | + 210 |
| Rankine (organic) | 4.3 | 3,320 | - | - | 3,320 | + 760 |
| Rankine (future organic) | 6.0 | 2,380 | - | - | 2,380 | - 180 |
| Stirling | 6.4 | 2,210 | - | - | 2,210 | - 350 |
| Battery electric[e] (present) | - | - | 1,440 | 2,250 | 3,690 | + 1,130 |
| Battery electric[e] (future) | - | - | 720[g] | 2,250[g] | 2,970[g] | + 410[g] |
| Hybrid[e] (ICE - electric) | 10.2 | 1,390 | -[f] | 750 | 2,140 | - 420 |

(a) ICE = Internal Combustion Engine.

(b) Base case for ICE is 2763.1 litres of fuel per year at 9.2¢ US per litre. No difference in price for alternative fuels is assumed.

(c) Assuming a US average of 1.5¢ US per kWh at customer's location.

(d) Medium-displacement V-8 in urban driving.

(e) Performance: 10 kW (present electric), 30 kW (future electric), 60 KW (hybrid).

(f) Some driving patterns would require supplementary battery charging.

(g) Future values uncertain.

Source: Ayres and McKenna (Ref. 3).

TABLE 5.16 - ESTIMATED TEN-YEAR MAINTENANCE COSTS FOR ALTERNATIVE POWER SYSTEMS, US

($US)

| Power system | Major repairs | Transmission maintenance | Minor repairs, tune-up | Working fluids, oil, filters | Estimated total cost | Cost difference from standard ICE |
|---|---|---|---|---|---|---|
| ICE[a] (spark ignition) | 500 | 200 | 800 | 280 | 1,780 | |
| Diesel | 300 | 250 | 200 | 320 | 1,070 | -710 |
| Gas turbine (regenerative) | 300 | 150 | 400 | 100 | 950 | -830 |
| Rankine[b] (steam) | 600 | 50 | 400 | 400 | 1,450 | -330 |
| Rankine[c] (future organic fluid) | 300 | 150 | 200 | 340 | 990 | -790 |
| Stirling | 500 | 150 | 200 | 300 | 1,150 | -630 |
| Battery electric[d] (present) | 200 | - | 100 | 50 | 350 | -1,430 |
| Battery electric[e] (future) | 200[f] | - | 100[f] | 50[f] | 350[f] | -1,430[f] |
| Hybrid (ICE - electric) | 600 | 150 | 900 | 280 | 1,930 | +150 |

(a) ICE = Internal Combustion Engine

(b) Incomplete condensing.

(c) Complete condensing.

(d) Lead-acid battery.

(e) Possible future battery, such as sodium sulphur.

(f) Future values uncertain.

Source: Ayres and McKenna (Ref. 3).

TABLE 5.17 - NET TEN-YEAR COST DIFFERENCES BETWEEN INTERNAL COMBUSTION ENGINE AND ALTERNATIVES, US

| Power system | Difference from 1970 ICE ($US) | Difference from 1975 ICE ($US) |
|---|---|---|
| ICE[a] (spark ignition) | 0 | 0 |
| Diesel | - 902 | n.a. |
| Gas turbine (regenerative) | + 830 | + 390 |
| Rankine[b] (steam) | + 180 | - 260 |
| Rankine[c] (organic fluid) | + 462 | + 22 |
| Rankine[c] (future organic fluid) | - 760 | - 1,200 |
| Stirling | + 508 | + 68 |
| Battery electric[d] (present) | + 912 | + 472 |
| Battery electric[e] (future) | + 24[f] | - 416[f] |
| Hybrid (ICE - electric) | + 774 | + 334 |

(a) ICE = Internal Combustion Engine.

(b) Incomplete condensing.

(c) Complete condensing.

(d) Lead-acid battery.

(e) Possible future battery, such as sodium-sulphur.

(f) Future values uncertain.

Notes: Ten-year costs include: first cost plus 20% interest on the first cost if it is over $50; cost of fuel energy (shown in Table 5.15) and maintenance costs for the power system (shown in Table 5.16).

n.a. = not available.

Source: Ayres and McKenna (Ref. 3).

TABLE 5.18 - FORECAST EFFECTS OF USING ELECTRIC ENERGY FOR CARS IN ITALY

| Variables (x $10^6$) | 1980 | 1990 | 2000 |
|---|---|---|---|
| Total number of cars | 19.00 | 23.00 | 26.00 |
| Cars registered in principal towns (50%) | 9.50 | 11.50 | 13.00 |
| Electric cars forecast | 0.95 | 3.45 | 7.80 |
| Total fuel consumption forecast (litres) | 20,900.00 | 25,300.00 | 28,600.00 |
| Fuel consumption forecast in urban agglomerations (litres) | 10,450.00 | 12,650.00 | 14,300.00 |
| Number of litres saved with electric cars | 1,045.00 | 3,795.00 | 8.580.00 |
| Corresponding tonnes of fuel saved (density = 0.720) | 0.75 | 2.73 | 6.18 |
| Number of km covered with this fuel saved | 9,405.00 | 34,155.00 | 77,220.00 |
| Number of kWh necessary to cover these km | 1,022.01 | 3,711.51 | 8,391.24 |
| Tonnes fuel oils necessary produce these kWh | 0.23 | 0.83 | 1.88 |
| Tonnes crude oil necessary to obtain fuel oils (54% output) | 0.42 | 1.54 | 3.48 |
| Tonnes crude oil necessary to obtain the petrol saved by electric cars (15.5% output) | 4.85 | 17.63 | 39.86 |

Source: Barbiroli (Ref. 4).

## CHAPTER 6 TRENDS AND FORECASTS

It is far from easy to predict the likely pattern of energy consumption for, say, the year 2000. The prices currently paid for basic fuels in Australia are unlikely to remain stable over the next few years. As the price of imported oil, for example, rises (as it undoubtedly will do), other forms of fuel or sources of petroleum energy supply will move towards economic feasibility. Winning oil from shale, for instance, has been tipped into marginal feasibility in North America by the rising cost of purchasing imported Middle East crude.

The extent to which changing price patterns influence the reorganisation of fuel supply and usage is, of course, the key question in predicting future patterns of energy consumption by transport, and in this initial literature review it is only appropriate to comment on published indicators and forecasts of the likely chain of events. Such analyses, based on a study of likely fuel prices and the elasticities of demand for the various fuels, are simply not available. In many cases, published predictions are often little more than conjecture, with indications of the economics of substitution or evolution of new transport and fuel technologies couched in general terms of the relative availability of the respective fuel sources. Thus, the discovery of large resources of natural gas in Australia is often taken (not admittedly, in this case, unreasonably) to be sufficient justification for the assertion that the proportion of total energy consumption which is served by natural gas will increase. The rate at which these processes are predicted to occur are as often as not simple extrapolations of recent trends, although the Department of National Development (Ref. 27) and the Department of Minerals and Energy (Refs. 25 and 26) provide welcome justification for their forecasts.

### TOTAL ENERGY CONSUMPTION

A discussion has been presented in Chapter 3 of the close relationship between per capita energy consumption and GNP, both cross-sectionally and historically. On the basis of this relationship, predictions of GNP and likely developments in the fuel supply and industrial sectors, the Department of Minerals and Energy (Ref. 25) predicted a reasonably constant rate of increase of total energy consumption of about 6.6% per annum to the year 1984-85. Consumption in 1984-85 is expected to be about $5176 \times 10^{12}$ kJ ($4907 \times 10^{12}$ BTU). This represents a consumption of approximately $317 \times 10^{6}$ kJ/head (the US in comparison, is forecast to use about $473 \times 10^{6}$ kJ/head in 1980). The Department's forecast of national consumption of each of the energy types is reproduced in Table 6.1.

Petroleum fuels are of primary importance to the transport sector. The Department of Minerals and Energy (Ref. 25) expects the total consumption of petroleum fuels to increase from $1111.0 \times 10^{12}$ kJ ($1053.2 \times 10^{12}$ BTU) in 1971-72 at a rate of 5.0% p.a. to $2165.8 \times 10^{12}$ kJ ($2053.2 \times 10^{12}$ BTU) in 1984-85. By 1999-2000, the use of petroleum fuels could exceed 2.3 million barrels a day, as shown in Table 6.2.

By the year 1999-2000, the expected cumulative demand as a percentage of the present known indigenous reserves of each fuel is as follows:

| | |
|---|---|
| Black coal | 13% |
| Brown coal | 18% |
| Petroleum fuels | 820% |
| Natural gas | 75% |

Obviously, present known reserves are only evaluated in terms of the amount of resource which may economically be exploited at present fuel prices. The likely increase in the price of petroleum products will have the effect of increasing the reserves of crude oil; existing reserves will be expanded, and new sources found. The magnitude of the figures, however, do suggest an insufficient potential supply of crude oil, and the implications of this as far as transport is concerned are important. The high demand/reserves ratio does suggest the likelihood of significant price rises for petroleum, with

TABLE 6.1 - FORECAST CONSUMPTION OF PRIMARY FUELS ASSUMING NO SIGNIFICANT NEW SOURCES OF ELECTRICITY PRODUCTION OR CONSUMPTION

(expressed in $MJ \times 10^9$) figures in brackets represent percentages of total consumption)

| Fiscal year | Black coal | Brown coal | Petroleum fuels | Wood and bagasse | Natural gas | Hydro-electricity[a] | TOTAL |
|---|---|---|---|---|---|---|---|
| 1971-72 | 665.9(29.8) | 236.1(10.6) | 1105.9(49.5) | 82.5(3.7) | 101.7(4.5) | 41.9(1.9) | 2234.0(100.0) |
| 1974-75 | 870.1(31.1) | 270.3(9.7) | 1342.6(48.0) | 80.7(2.9) | 187.0(6.7) | 45.6(1.6) | 2796.3(100.0) |
| 1979-80 | 1050.2(27.3) | 353.1(9.2) | 1656.7(43.0) | 80.3(2.0) | 660.6(17.2) | 49.5(1.3) | 3850.4(100.0) |
| 1984-85 | 1367.4(26.6) | 537.6(10.4) | 2155.9(41.8) | 82.0(1.6) | 951.1(18.5) | 58.1(1.2) | 5152.1(100) |
| 1989-90 | 1722 (26) | 704 (11) | 2814 (42) | 84 (1) | 1292 (19) | 63 (1) | 6679 (100) |
| 1994-95 | 2184 (25) | 966 (11) | 3738 (42) | 84 (1) | 1775 (20) | 63 (1) | 8810 (100) |
| 1999-2000 | 2751 (23) | 1344 (11) | 5019 (43) | 84 (1) | 2426 (21) | 63 (1) | 11687 (100) |
| Growth rate, % p.a. | | | | | | | |
| 1971-72 to 1984-85 | 5.2 | 6.4 | 5.0 | 0 | 19.6 | 2.0 | 6.6 |
| 1984-85 to 1999-2000 | 4.8 | 6.7 | 5.8 | 0 | 6.5 | 0.6 | 5.7 |

Note: Forecasts beyond 1984-85 are approximate only.

Source: Department of Minerals and Energy (Ref. 26).

TABLE 6.2 - FORECAST CONSUMPTION OF PETROLEUM FUELS

(Barrels x $10^3$; figures in brackets represent percentages of total consumption)

| Fiscal year | Gasolines (a) | Middle distillates (b) | Heavy fuels (c) | Other fuels (d) | TOTAL |
|---|---|---|---|---|---|
| 1971-72 | 70,679(37.6) | 38,796(20.6) | 55,812(29.7) | 22,689(12.1) | 187,980(100.0) |
| 1974-75 | 82,580(36.3) | 49,699(21.8) | 66,570(29.2) | 28,851(12.7) | 227,700(100.0) |
| 1979-80 | 108,180(38.3) | 79,808(27.2) | 65,000(23.0) | 32,302(11.5) | 282,290(100.0) |
| 1984-85 | 141,900(38.6) | 198,721(29.5) | 75,255(20.4) | 42,374(11.5) | 368,250(100.0) |
| 1989-90 | 183,400(38.2) | 159,000(33.2) | 85,830(17.9) | 51,340(10.7) | 479,600(100.0) |
| 1994-95 | 237,100(37.2) | 234,700(36.8) | 97,910(15.3) | 68,400(10.7) | 638,100(100.0) |
| 1999-2000 | 305,700(35.7) | 347,900(40.6) | 111,700(13.0) | 91,840(10.7) | 857,200(100.0) |

(a) Aviation gasoline, petrol, power kerosene.

(b) Aviation turbine fuel, lighting kerosene, heating oil, automotive distillate.

(c) Industrial diesel fuel, furnace oil.

(d) LPG refinery gas sales, naptha, refinery fuel.

Source: Department of Minerals and Energy (Ref. 26).

the effect that alternative sources of transport fuel will become increasingly more economically feasible to develop. Whether or not the demand for transport mobility itself will be suppressed is a matter which will require further study. No published material has been found to indicate the elasticity of transport demand with respect to changes in the prices of transport fuels in Australia.

THE DEMAND FOR TRANSPORT FUELS

The literature survey described in this report revealed no authoritative forecast of the consumption of fuel in the transport sector in Australia. Even if forecasts had been made in the past, the bases for the analyses would have been changed considerably by recent events in the petroleum industry.

Putting aside for the moment the question of the short-term realignment of transport fuel costs, it is worthwhile considering the changing patterns of fuel usage which have resulted from the observed development of transport technologies. Although it may be argued that the fuel price changes likely in the next few years may tend to disrupt the patterns of evolution of transport demand which have been the historical response to comparatively stable price changes, the patterns themselves and, equally important, popular expectations of a standard of mobility, may be sufficiently well established to justify the argument that new fuel or power technologies will respond to these patterns of demand rather than vice versa.

Clark (Ref. 14) has argued that with increasing affluence, the individual's increasing valuation of his own time will cause him to demand a faster means of transport. Drawing from research results he points out that rather than reducing total travel time, these faster transport technologies simply permit the individual to travel a greater distance within what is thought to be a reasonably constant allocation of hours per annum for travel. Thus, a faster means of travel will have the effect of increasing the total amount of travel demanded. The increasing number of kilometres travelled per person per annum he has called the 'standard of mobility'. Historical examples show that the standard of mobility is greater when there is a greater availability of faster means of transport, both cross-sectionally between countries and over time.

The standard of mobility in 1969-70 in Australia was approximately 8,500 person-km/head, and is likely to increase dramatically in line with expected increases in real income per head. On present indications, this increase in mobility is likely to occur through greatly increased usage of air transport.

The energy-intensiveness of the faster means of travel, in particular road and air modes, is greater than for other modes; i.e., road and air transport, in general, consume more energy per tonne-km or per passenger-km than do, for example, rail or sea modes. These conclusions are confirmed by Rice (Ref. 59), in a study of the evolution of technologies of transport, and Mooz (Ref. 52) in an analysis of the effect of fuel price increases on the energy intensiveness of freight transport in the US. Typical figures for the energy intensiveness of various modes of transport are presented in Tables 4.4 and 4.5.

Tables 6.3, 6.4 and 6.5 develop the possible pattern of use of the various modes assuming a travel time budget of 500 hours per annum per individual. Table 6.5 in particular shows how the use of transport modes may adjust to the demand for faster means of travel, with considerable implications for energy usage. The faster modes have been generally shown in Tables 4.4 and 4.5 to utilise more energy per passenger-km or tonne-km. These implications could be of dramatic importance in the light of Australia's known resources of fuel applicable to the car and air modes.

TABLE 6.3 - TYPICAL CHARACTERISTICS OF TRANSPORT MODES

| Travel mode | Approx. journey speed (km/hr) | Distance travelled in 500 hrs (km) | Cost (¢/km) | Minutes per km |
|---|---|---|---|---|
| Walk | 5 | 2,500 | 0 | 12 |
| Bicycle | 10 | 5,000 | neg. | 6 |
| Bus-tram | 10-15[a] | 5 - 7,000 | 3[a] | 5 |
| Train | 15-20[a] | 7 - 10,000 | 3[a] | 3 |
| Urban car | 30 | 15,000 | 5-15 | 2 |
| Car on freeway | 45 | 22,500 | 5-15 | 1-3 |
| Aeroplane | 300[a] | 150,000 | 5[a] | 0.2 |

(a) Actual values depend on stage length.

Source: Clark (Ref. 14).

TABLE 6.4 - DEMAND FOR TRANSPORT IN AUSTRALIA

| Personal travel mode | km/person 1969-70 | km/person 1959-60 | Freight mode | Tonne km/person 1969-70 | Tonne km/person 1959-60 |
|---|---|---|---|---|---|
| Walk/bicycle | 500 | 750 | Rail | 2,610 | 1,280 |
| Bus | 300 | 395 | Road | 2,000 | 1,270 |
| Train | 775 | 975 | Sea (coastal)[a] | 5,160 | 2,900 |
| Car/motor cycle | 6,400 | 4,040 | | | |
| Air (domestic) | 375 | 155 | Total | 9,770 | 5,450 |
| Air (international) | 200 | 85 | | | |
| Total | 8,550 | 6,400 | | | |

(a) In addition, in 1970-71, 100m tonnes (approx.) of freight were shipped for overseas ports and 25m tonnes (approx.) discharged in Australia. If one half of this freight is credited to Australia, and the average journey is taken as 10,000 km, overseas freight contributed 625 x $10^9$ tonne-km in 1970-71; i.e., 50,000 tonne-km/head per year.

Source: Clark (Ref. 14).

TABLE 6.5 - POSTULATED USE OF MODES AT VARIOUS STANDARDS OF MOBILITY

| | | | | | |
|---|---|---|---|---|---|
| Car ownership rate (persons per vehicle) | 100 | 10 | 4 | 2.5 | 2 |
| Annual distance travelled on each mode (km per person) - | | | | | |
| - Motor car | 250 | 2,150 | 5,250 | 7,500 | 9,000 |
| - Bus/train | 250 | 1,500 | 1,125 | 1,000 | 1,000 |
| - Air | 0 | 100 | 375 | 1,000 | 2,000 |
| - Walk/bicycle | 2,000 | 1,250 | 750 | 500 | 500 |
| Standard of mobility (km/person) | 2,500 | 5,000 | 7,500 | 10,000 | 12,500 |

Source: Clark (Ref. 14).

THE PRICE OF FUEL AND ITS EFFECT ON TRANSPORT DEMAND

Fundamental to the majority of travel forecasting studies reported in the literature is an underlying assumption of relative stability in fuel prices. And yet it is well recognised that the demand for any commodity, including travel, is influenced to some extent at least by its cost. The extent to which this is so depends on the elasticity of that demand to price changes.

The elasticity of demand for transport might be expected to be influenced by the price of fuel in some relation to average weekly earnings. As Table 6.6 shows, by 1972, the average weekly earnings per employed male unit (all civilian males plus approximately 52.5% of employed females) had increased 426.5% (in money values) since 30 June 1949, while the retail price of standard grade petrol in Australia has increased only 69% during the same period. Thus, in 1972, 10 gallons of petrol cost only 4.9% of average weekly earnings, compared with 15.3% in 1949 (Petroleum Information Bureau, (Ref. 59)). Obviously, these figures take no account of the distribution of earnings of car owners, but they do suggest that the average Australian car driver might regard the unit cost of petrol as an insignificant portion of his weekly budget. Certainly, for an average urban journey, the cost of petrol now appears small in relation to the individual's expenditure of his own travel time, generally valued at between 25% and 30% of his wage rate. Thus, for example, a 13 km journey by car costs approximately 17¢ for petrol, but at least 80¢ to $1.00 in perceived time costs.

Mooz (Ref. 52), in a US study of the effect of fuel price increases on the energy intensiveness of freight transport, does not directly tackle an analysis of the effect of price changes on demand, but suggests that in the event fuel prices increase, the competitive position of freight modes would be altered and modal redistribution might result. In general, fuel price changes would tend to affect each mode in proportion to its energy intensiveness

TABLE 6.6 - COMPARISON OF PETROL PRICES, AVERAGE WAGES AND RETAIL PRICES

| Year | Average weekly earnings per employed male unit $ | Increase since 1949 % | Consumer price index (1966-67 = 100) | Increase since 1949 % | Retail price (cents) per litre standard petrol | Increase since 1949 % |
|---|---|---|---|---|---|---|
| 1949 | 17.70[a] | - | 43.9 | - | 5.96 | - |
| 1962 | 47.60 | 168.9 | 89.6 | 104.1 | 7.46 | 25.2 |
| 1963 | 48.90 | 176.3 | 89.8 | 104.6 | 7.46 | 25.1 |
| 1964 | 51.50 | 191.0 | 90.6 | 106.4 | 7.39 | 24.0 |
| 1965 | 55.30 | 212.4 | 94.0 | 114.1 | 7.35 | 23.3 |
| 1966 | 57.90 | 227.1 | 97.4 | 121.9 | 8.00 | 34.2 |
| 1967 | 61.70 | 248.6 | 100.0 | 127.8 | 8.22 | 38.0 |
| 1968 | 65.30 | 268.9 | 103.3 | 135.3 | 8.47 | 42.1 |
| 1969 | 70.20 | 296.6 | 106.0 | 141.5 | 8.60 | 44.3 |
| 1970 | 76.10 | 329.9 | 109.4 | 149.2 | 8.84 | 48.3 |
| 1971 | 84.70 | 378.5 | 114.6 | 161.0 | 9.61 | 61.2 |
| 1972 | 93.20 | 426.5 | 122.2 | 178.4 | 10.07 | 69.0 |

(a) Estimated.

Source: Petroleum Information Bureau (Ref. 57).

(i.e., energy consumed per tonne-km) so that changes between average modal rates would be a function of the differences in their energy intensiveness. For all surface transport modes, these changes are of relatively small effect compared with those for air transport. Because the energy intensiveness of air transport is estimated as between 26 and 126 times the intensiveness of other modes, air transport would feel the effect of fuel price increases the most, and the growth of freight traffic by air transport would tend to be inhibited. Any appreciable decrease in the growth rate of air freight traffic would have a significant effect on the total average energy intensiveness of freight transport.

For the passenger market, the extent to which demand is inhibited by price increases will depend, at any particular time, on the fuel price in relation to real income and the individual's valuation of his time. It might be concluded from the evidence above that major price rises would be required to cause a significant alteration to the trend towards faster modes, but forecasts of the magnitude of changes in passenger travel require further study.

## OTHER FACTORS AFFECTING THE DEMAND FOR TRANSPORT ENERGY

There is ample evidence of an increasing overall demand for transport, not only in the material reviewed above but also in the numerous transport study reports undertaken for the majority of the larger urban areas in Australia and in the published statistics of authorities responsible for the operation or regulation of transport services. Clark (Ref. 14) summarises much of this information in a manner pertinent to the objectives of this study, and any additional analysis of the literature on the increasing demand for transport in Australia would add little further at this stage.

It is worthwhile, however, to examine briefly, in the light of Clark's paper, some of the fundamental evolutionary changes in community behaviour which have contributed to the increased use of transport. For instance, the increasing standard of mobility suggests that faster modes of travel encourage a greater number of overall vehicle kilometres travelled. If a reasonably constant travel time budget may be accepted (it finds some confirmation in work undertaken by McMeckan (Ref. 50)), the surplus travel time freed by the use of faster modes for the journey to work is likely to be used for recreational, social and other travel purposes. Again, the increase in travel undertaken for these purposes is confirmed in the literature, for example, in Roscholler (Ref. 59). It has significant effects on the pattern of energy usage. Recreational travel, to take an example, is commonly undertaken by car or, increasingly, by air, the two most energy intensive modes. In fact, as Roscholler shows, the majority of arterial roads in the outer fringe areas of Australian metropolitan regions now carry their peak vehicle flows during the weekend.

Recent trends in urbanisation also contribute towards higher energy usage by encouraging a reliance on the private car and an increase in average trip lengths. These trends take root in the ability of the private car to permit greater distances of journey-to-work travel within the same travel time budget.

It is not appropriate to develop these themes of discussion further in this section of the report. The comments above are not directly derived from published papers - to approach such a task in this complex aspect of the study would require more time than is available - but they do relate to important changes in the patterns of energy usage and should be considered in later studies.

Other factors which may be expected to influence patterns of transport energy usage include urban development and transport regulatory measures designed to reduce travel: such measures, for example, as petrol rationing; discriminatory fuel pricing and vehicle registration and excise levies; pricing incentives to encourage travel by public transport; and restrictions or levies on particular categories of travel, such as central city access by private car. In each of these cases a review of the literature has identified little of direct value to Australian conditions. There exists, therefore, a strong argument for an original assessment of the effects of specific policy measures on the demand for transport energy under Australian conditions.

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