

Centre for Resource  
and Environmental Studies,  
The Australian National  
University, 1980

UNESCO/UNEP  
Papua New Guinea Human Ecology Programme:  
Lae and Its Hinterland

# Report No.4 Energy for Development: the energy policy papers of the Lae Project

Ken Newcombe  
with Kaye Bowman,  
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PREFACE TO REPORT No.4, Papua New Guinea Human Ecology Programme

The present volume is one of a series reporting the findings of the Papua New Guinea Human Ecology Programme. This Programme has been conducted within the framework of Unesco's Man and the Biosphere Programme, Project Area No. 11 (MAB 11), which is concerned with integrated ecological studies on human settlements. The Programme has been under the leadership of Dr. Ken Newcombe of the Centre for Resource and Environmental Studies of the Australian National University. It has been supported financially by Unesco, UNEP and the Australian National University.

The aim of MAB 11 is to promote an integrative ecological approach to the study and planning of human settlements. This involves the systematic analysis and description of the dynamic ecological interrelationships within settlements and between settlements and their hinterlands, and then the application of the integrative concepts and methods developed in this work to policy formulation and planning for the future. The projects are concerned with changing patterns of flow and of use of energy and of resources, and with the implications of these changes both for the relationship between human societies and the natural environment and for the quality of life of people living in the settlements and their hinterlands.

MAB 11 puts a great deal of emphasis on the need for effective interaction between research workers on the one hand and planners and decision-makers on the other, and it advocates the active involvement of the latter group in MAB 11 projects.

The Papua New Guinea Human Ecology Programme is entirely consistent with these aims and objectives of MAB 11. The work on the City of Lae and its hinterland has been concerned with such important ecological considerations as the following:- patterns of energy use, and in particular alternative and renewable sources of energy in the future; changing dietary habits; the various social impacts of the introduction of the money-based economy and of consumerism; and the effects of changing societal conditions on life style and health and well-being. There has been active participation by members and staff of the Lae City Council and of the University of Technology at Lae at all stages of the Programme.

The emphasis in the present volume, which has been prepared by Dr Newcombe, is on patterns of energy use in the study area and with

alternative energy sources for the future. Other volumes in the series are "From Kaukau to Coke: A study of rural and urban food habits in Papua New Guinea" by D. Jeffries (1979); "Chimbu People under Pressure: The social impact of urbanisation" by J. Dalton (1979); "Consumer Behaviour in Papua New Guinea: Its social and ecological implications" by M. Christie (in press).

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Second in order, but first in importance, are the individuals who have been directly and indirectly involved during the long period of research. I am grateful to Professors Stephen Boyden and Frank Fenner, for their efforts in facilitating the research programme, and I am fortunate to have had the benefit of a thoughtful and dedicated team of co-workers in James Pokris, Marion Christie, and in particular, Kaye Bowman. None of this research would have been documented, though, without constant effort, under trying circumstances, by Fay Goddard at CRES. Mrs Goddard provided the link between my Papua New Guinea base and the ANU, and translated and typed all of my difficult handwriting in addition to an already full workload at CRES. This was a personal contribution for which I am truly grateful.

Once having joined government to build on the experience of this research, and to formulate a policy and programme of implementation, I enjoyed a fulfilling learning experience through interaction with my many colleagues there. The transition from theory to application, which is still taking place, is reflected subtly in the many changes between this final manuscript and the initial technical papers from which it has been derived. In government I have benefited greatly from my association with my close colleague Larry Weick, Power Systems Planner in the tiny Energy Planning Unit of this period.

I must also acknowledge the patience and understanding of John Celecia of UNESCO to whom, until now, we have presented an embarrassingly small number of reports, in relation to those contracted for, and those still in preparation.

Of course, and as ever, what is now presented is here only through the unselfish support of my work by my wife and the sacrifice of time with my family.

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## Chapter 1

The Policy Context

This UNESCO/UNEP sponsored study has been conducted within the framework of the Man and the Biosphere (MAB) Programme, Project Area No.11, which is concerned with integrated ecological studies on human settlements. While much of this research deals with relationships and interactions between component parts of settlements, the ecology of a settlement is of necessity a function of its relationships with its hinterland; its surrounding, or distant and disaggregated catchment areas for information, materials, energy and people. Therefore the study of the ecology of a city is also the study of its growth, or decline, as a centre of activity and population; a study of the dynamics and consequences of urbanization.

In the research reported here we are concerned primarily with energy flow and end use, and thereafter with the potential for alternative patterns of supply, and alternative sources of energy which serve the ecological goals of stability and long term viability, compatible with the integrity of natural ecosystems and with human well-being.

UNESCO has defined the objectives of MAB 11 as both descriptive and policy-oriented, as inferred in the Report of the Task Force on MAB 11 (UNESCO, 1976).

"(1) The study of systems of settlements, or particular settlements and their components as ecological systems with particular reference to input-output studies, or budgets of material and energy flow combined with the analysis of interrelationships between these processes of the settlement system and human well-being.

(2) The study of the interaction between the human settlement (or settlement pattern) and the natural ecosystem of which it is part, with particular attention to the short and long term effects of each on the other, the capacity of the natural system to support human activity, and the need to plan for maximum sustainable use and conservation of natural resources."

Overlaying the goals of UNESCO and UNEP in MAB 11, which are in fact determined by a globally representative council of nation

states, is the policy manifestation of the aspirations for development of the nation state in which these studies take place.

Papua New Guinea is a newly independent nation state, gaining its Independence from Australia, which held responsibility for its administration as a Trust Territory, in September 1975. Within a year of Independence Papua New Guinea's leaders had determined the elements of a national development strategy (Nat. Planning Committee, 1976).

It was with this development strategy in mind that research proceeded in Papua New Guinea, and with the advice of the administration, specifically on Lae and its hinterland.

The 'eight point plan' for development in Papua New Guinea was as follows:

- 1) A rapid increase in the proportion of the economy under the control of Papua New Guinean individuals and groups, and in the proportion of personal and property income that goes to Papua New Guineans.
- 2) More equal distribution of economic benefits, including movement toward equalization of incomes among people and toward equalization of services among different areas of the country.
- 3) Decentralization of economic activity, planning and government spending, with emphasis on agricultural development, village industry, better internal trade, and more spending channelled to local and area bodies.
- 4) An emphasis on small scale artisan, service and business activity, relying where possible on typically Papua New Guinean forms of business activity.
- 5) A more self-reliant economy, less dependent for its needs on imported goods and services, and better able to meet the needs of its people through local production.
- 6) An increasing capacity for meeting government spending from locally raised revenue.
- 7) A rapid increase in the equal and active participation of women in all forms of economic and social activity.
- 8) Government control and involvement in those sectors of the economy where control is necessary to achieve the desired kind of development.

All but the seventh point of this eight-point plan can be satisfied, directly or indirectly, by the development of an energy strategy which

emphasises the maximum economic use of locally available renewable energy resources. The following chapters of this report define the absolute amounts and the patterns of energy use in brief overview for the economy as a whole, and in detail for the city of Lae. Lae was expected to be typical of the context of energy use and the features of urbanization as they affect energy and material use and distribution. This view appears to be vindicated following the experience of the last three years, 1977-80, for the options for alternative energy development and management are truly options for much of the rest of the country.

There are several important considerations that must be borne in mind when evaluating the policies and programmes arising from this research.

In the first instance an energy economy based on solar derived sources, such as biomass, direct solar radiation and, to a lesser extent, wind or hydro-power, is closely compatible with a development strategy emphasising decentralization, equal distribution of benefits and services and small scale artisan activities, because, by their nature, solar energy forms are diffuse and distributed. Indeed considerable effort and expense must be applied to concentrate solar energy forms, which is one reason why solar based energy strategies suffer economic disadvantages in industrialized-urbanized nations where population and economic activity is highly centralized and energy-intensive.

Conversely it is no coincidence that renewable solar-derived energy forms are directly compatible with the already dispersed energy needs of the non-urbanized countries of the Pacific region.

It is clear that many of the alternative renewable sources of energy available in the tropical regions are accessible and manipulable with techniques and technology able to be completely under the control of rural or village peoples, and can add reasonably to their quality of life. Here we can refer to very sophisticated technology such as photovoltaic cells through to more simple though efficient and convenient charcoal production and cooking devices.

A further aspect of policy arises from the use of biomass fuels as part of an energy strategy to exploit locally available renewable energy forms. It is essential to view energy production

in this context as just one part of a production system providing, as well, food and other essential materials. Furthermore, the pattern of energy production will invariably affect or be influenced by culturally determined perspectives and social behaviour, and will have direct or subtle implications far beyond the thermodynamics of servicing a demand for a fuel.

Energy planning is thus intimately related to, and influential in, planning for food production and social change.

This is especially important in planning for the production of biomass fuels, for it is rare for there not to be potential for integrated complexes producing in addition, food or materials, that greatly influence, if not ensure, the ecological and economic viability of any programme ostensibly to produce just energy.

It is frequently true that an integrated ecological approach to energy production will lead to the development of production and management systems which have desirable consequences for the social well-being of communities as well as for food production and resource management in general. The present development of the City of Lae as an urban-agro-ecosystem (Newcombe and Pohai, 1979), arising from this MAB 11 project, is an example of this kind of development.

One final policy issue is the problem of trying to satisfy more than one development goal at the one time. It is often the case for example that an import-substitution programme can be economically viable, can add to the existing array of rural industry and contribute to the general infrastructure required for rural development and provide employment, but cannot economically involve small-holders in the production process. Here a clear policy decision must be made by the government acknowledging the limitations presented and addressing the net benefits of the increased self-reliance and independence.

In the overview of developing countries in the Asia-Pacific region there is one salient feature which impinges upon the formulation of an energy policy. It is that they are, with few exceptions, non-urban societies, now subject to rapid urbanization. If there is a desire expressed in the guiding philosophy of the particular nation's development strategy to constrain the rate of urbanization, and to focus resources on balanced rural development, then this broadly

defines the energy policy of the nation. The energy policy of the country must, on the one hand, aim to sustain and stabilise the supply and production of fuels in customary use in the village sector and supplement these with whatever new, and truly beneficial energy sources and related technologies which do confer an addition to the quality of life of rural people and which simultaneously give rise to an equitable distribution of the nation's development expenditures.

On the other hand it must be acknowledged that not only is continued urbanization inevitable, and that at a minimum cities will continue to grow in size, but that urban settlements are the location of the majority of the demand for imported petroleum fuels. There is an argument, which can be put convincingly, that urbanization is the natural corollary of economic development. Bearing these facts, trends, and perceptions in mind, it is important to ensure that the patterns of urbanization and urban planning are sensitive to the energy costs and evolve an energy efficient infrastructure for urban life in order to reduce the burden of urbanization on the nation as a whole, and to enable the vision of balanced rural development some chance of realisation. Maximising the use of energy and nutrients naturally available within urban centres through the creation of integrated complexes of resource management, involving organic cycling and energy extraction, is entirely consistent with balanced rural development because it reduces the economic burden of urban welfare and reduces the demand the urban settlement makes on its hinterland for food, energy and resources.

The chapters contained in this volume deal particularly with the options for transferring the population of Lae to a renewable energy base. Other volumes will deal with the construction of essential cycles of nutrients, and energy and resource recovery within the city, and with the rural component in this study of the rural-urban dynamics of Lae and its hinterland.



Chapter 2

Energy and Urbanism in Papua New Guinea:

The Industrial City of Lae

## INTRODUCTION

Papua New Guinea is a small, recently independent, Third World state in the South Pacific. Late last century, and in the early years of this century, the New Guinea section, or the northern half of Papua New Guinea, was subjected to the control of a German administration, mostly through German trading companies and missionaries. Although this early influence is still detectable, it has been the succession of Australian governments who took over administration during World War I, and who gained the Territory of Papua New Guinea as a protectorate after World War II, that have developed the economy and moulded much of the physical and social context in which current planning and resource management is set (Willis, 1974). It is a Western industrial mode of development with Australian variations on the general theme, that is the legacy of this Third World state, and which has determined its current pattern of commercial energy supply and demand. Economic development so far in Papua New Guinea has been biased greatly towards an urban industrial base, and this, as we shall see, is clearly reflected in the patterns of energy flow.

This nation has therefore developed a large and rapidly growing dependency on imported petroleum products, and little effort has been made to date to develop plentiful indigenous renewable energy sources. Papua New Guinea also imports significant quantities of energy-intensive goods, such as iron and steel products, cement, nitrogenous fertilisers and, most importantly, in excess of one-quarter of its total food requirements. (Shaw, 1978).

Up until Independence, the Australian administration and business community dominated urban-based consumption and dictated, through market forces, the formulation of a large trade in imported consumer durables, imported foodstuffs and luxury items such as motor vehicles, and created a profitable trade in cigarettes, soft drinks and beer. From the history of Third World development all of these trends might have been anticipated, and it is not the purpose of this paper to make comment on their social value, other than to emphasise that they are, for the most part, energy-intensive habits, cultivating the use of increasingly scarce energy forms in an economy unable to

buffer the pressure of multiplying energy prices that are certain to be part of Papua New Guinea's future. In other words, acknowledging the perhaps unwitting deficiencies in previous planning in this respect, there is ample room, and great need, to create a less energy-intensive, more resource-conserving future, and to plan for economic development and human well-being within definable and inviolable ecological and thermodynamic limitations.

This research, part of the Papua New Guinea Human Ecology Programme, has been designed to delineate current patterns of energy use, and to evaluate the obstacles these represent to the achievement of stable development, and to propose policy for future energy and resource management in co-operation with all tiers of government, including informal village and settlement organisations.

#### Papua New Guinea in a global perspective

Papua New Guinea is located within the humid tropics, latitude  $2^{\circ}$ - $10^{\circ}$  south, and naturally shares much in common with tropical highland and lowland systems in South Asia and the South Pacific. Solar insolation is abundant and biological productivity is high, as is humidity and rainfall in most of the lowland coastal zones. Papua New Guinea's greatest natural assets from the energy viewpoint, are its forests and its hydro-power resources. There are about 15 million hectares of operable forest in Papua New Guinea, between 3 and 12 times more per capita than other countries with major forest resources in the Asian region (FAO, 1976). Even the vast areas of degraded but climax kunai grasslands in Papua New Guinea could constitute an invaluable resource for short rotation forestry, with energy as the key product (see Harris, 1978).

The population of Papua New Guinea, though only about 2,959,800 in 1978, is estimated to be growing at close to 3% per annum, with about 2.5% per annum growth in the rural population and up to 7.5% per annum for a large proportion of the urban population. Total energy supply in Papua New Guinea from imports in 1975-1976 was about 4 million barrels of oil equivalent (Mboe) or  $243 \times 10^8$  MJ. Total per capita consumption in 1976 was about 41MJ, of which 24MJ was imported petroleum products and 16MJ was firewood (estimated from Newcombe,

1979). Table 1, viewed in relation to Figure 1, indicates the fuel types utilised and the proportion they contribute to total end-use in per capita terms. Table 2 places the use of commercial energy forms, that is petroleum fuels and electricity, in the perspective of per capita energy use within South Asian, South Pacific and selected industrial states.

In the first instance, it is clear that the non-commercial energy form of firewood contributes close to 40% of primary energy use, and must take priority in energy planning, for it is, additionally, the fuel most commonly used by Papua New Guineans, being the predominant energy source in rural village communities. In fact, if the energy use by one major company, the Bougainville Copper Ltd. (BCL), amounting to 8.5MJ/capita, is excluded from the calculation, energy from forest biomass amounts to half the total energy use. It is an interesting reflection in itself that the size of the Papua New Guinean economy is such that one single multinational utilises 21% of the nation's energy just to generate its electricity requirements.

In relation to other countries in the region Papua New Guinea's per capita use of petroleum products is small, being roughly equivalent to that of India, and the Philippines. However, in a global context, its level of energy use is tiny, being 0.05% and 1.5% of the United States and Australian consumption respectively, and still only 70% of the per capita use in the developing world as a whole (U.N., 1975).

#### The modern energy forms

Papua New Guinea was not administered by a European power until the 1800's and even then contact between the Europeans and the indigenous population was minimal, being restricted to administrative posts in coastal areas served by boat and, later, in the 1920's, by aeroplane. Contact with the hinterland was by foot and perhaps the most important energy transformation which this contact occasioned was the greater efficiency of utilisation of muscle energy made possible by the use of European tools, such as steel axes (Salisbury, 1962). Road systems to the hinterland reached only tens of miles prior to World War II, which probably constituted the first contact of a genuinely high energy society with the neolithic communities of

Table 1 Imports and Production of Primary and Secondary Energy Forms

<u>1975-76</u>				
<u>Primary Energy</u>	Specified Units	MJ x 10 <sup>8</sup>	% of Total	MJ/Capita/Day
Petrol (benzine)	125.9Ml	43.17	10.5	4.2
Aviation fuels				
-'Avtur'	40.2Ml	14.62	3.5	1.4
-'Avgas'	18.0Ml	6.07	1.5	0.6
Distillates (diesel)	221.4Ml	84.12	20.4	8.2
Fuel oil	214.3Ml	88.50	21.5	8.6
Liquefied Petroleum				
Gas	5.6Ml	1.47	0.4	0.1
Kerosene	14.9Ml	5.48	1.3	0.5
Firewood	1.19Mte	161.10	39.2	15.7
Hydro-electricity	206.6GWhrs	7.44	1.8	0.7
<u>TOTAL</u>		411.97	100.1	40.0
 <u>Secondary Energy</u>				
Petrol (benzine)	125.9Ml	43.17	12.4	4.2
Aviation fuels				
- 'Avtur'	40.2Ml	14.62	4.2	1.4
- 'Avgas'	18.0Ml	6.07	1.8	0.6
Distillates (diesel)	198.8Ml	75.54	21.8	7.4
Fuel oil	12.9Ml	5.31	1.5	0.5
Liquefied Petroleum				
gas	5.6Ml	1.47	0.4	0.1
Kerosene	14.9Ml	5.48	1.6	0.5
Firewood	1.19Mte	161.10	46.5	15.7
Electricity				
- from Fuel oil	670.0GWhrs	24.12	7.0	2.4
- from Diesel	69.1GWhrs	2.49	0.7	0.2
- from Hydro	206.6GWhrs	7.44	2.1	0.7
<u>TOTAL</u>		346.81	100.0	33.7

Figure 1

RELATIVE SHARE of TOTAL ENERGY USE of MAJOR PRIMARY FUELS  
and ELECTRICITY

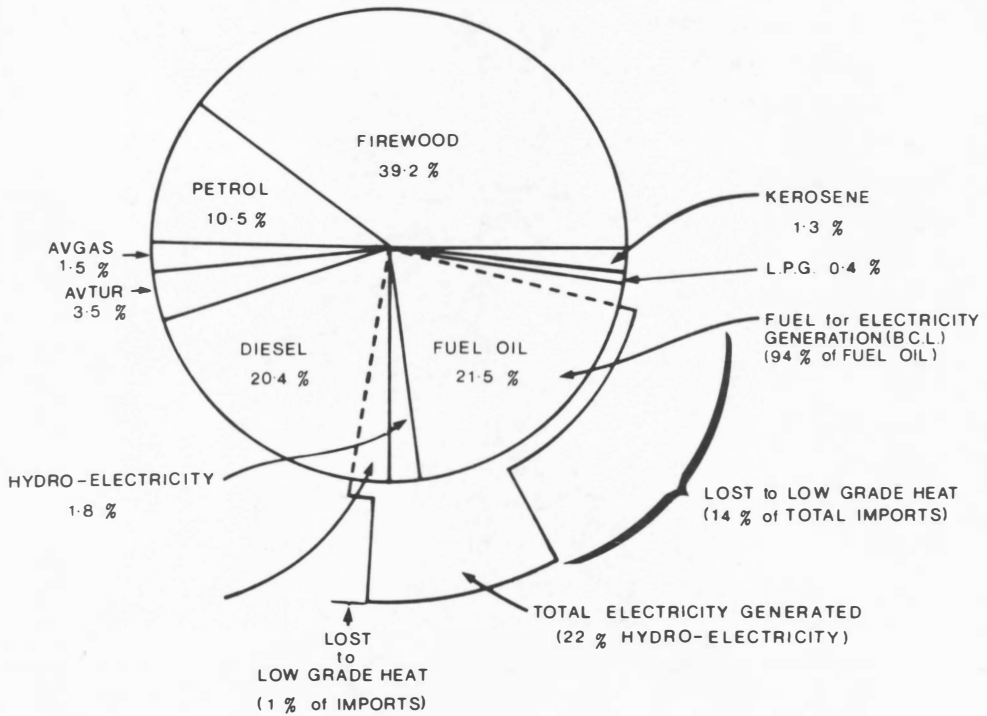


Table 2 Global and Regional Comparison of Energy Consumption  
with Papua New Guinea, 1975

Place	Primary Commercial Fuel (MJ/Capita/Day) <sup>1</sup>	Non-commercial Fuels	
		Fuelwood <sup>2</sup> Cubic Metre (or other) (MJ/Capita/Day)	Dung <sup>3</sup>
World	170		
Developed Countries*	510.7		
Developing Countries**	33.6		
Papua New Guinea	24.3	15.7 <sup>4</sup>	
Pacific Islands***	76.2		
New Hebrides	47.0		
Solomon Islands	20.2	16.2	
Fiji	48.8		
Australia	543.5	5.4	
Indonesia****	14.9		
India	18.5	4.3(11)	4.0
Tonga	12.8		
Philippines	27.3	11.5	
Japan	303.6		
New Zealand	260.7	2.6	
Nepal	0.84	13.1	

\* The developed market economies of Australia, Canada, Israel, Japan New Zealand, South Africa, United States and Western Europe (including Yugoslavia).

\*\* The developing market economies of Africa, Caribbean America, South America, other America, Middle East (including Turkey), Far East and Oceania.

\*\*\* Pacific Islands (Trust Territory) comprises the Caroline, Mariana and Marshall Islands except Guam.

\*\*\*\* Indonesia includes West Irian.

<sup>1</sup> Data derived from 'World Energy Supplies' 1950-1974, Statistical Papers Series J, No.20, United Nations, 1976.

1Kg of coal equivalent has been taken as 30.59MJ.

<sup>2</sup> ESCAP (1978) This data is clearly a guesstimate by ESCAP.

<sup>3</sup> REVELLE (1976).

<sup>4</sup> This research (see Newcombe et al, 1978).

Papua New Guinea. The occupying Japanese, Australian and American forces dramatically increased the energy intensity of human activity in a few short years, and laid in place a super-structure of roads and airports that facilitated rapid transition to the fossil fuel era for Papua New Guinea. In Morobe Province alone at the end of the Pacific War 40,000 Americans were stationed at Nadzab, then a large military airbase, and diesel fuel was pumped 40km from bunker storage at the wharves in Lae serviced by the U.S. fleet (H. Niall, pers. comm., 1978).

This is reflected in the trends of per capita energy use for the fossil fuels and electricity indicated in Figure 2a, which shows almost exponential growth in the use of these fuels, probably starting post-War, and ending in 1971-1972, with an alleged temporary exodus of Europeans from the Australian Trust Territory. This sudden stagnation in energy growth was repeated again during the energy crisis and pre-Independence periods. Table 3a provides the fine detail of changing growth patterns for each fuel type for the 20 year period. This information is summarised in Table 3b. During the last decade the major petroleum fuels showed an average growth rate per capita exceeding 8%, falling to 4% in the last four years (see Figure 2b). These recent fluctuations in energy growth provide only a very tenuous base for forecasting future energy demand, if the growth in energy use were left untrammelled by conservation and other energy management initiatives. Perhaps the most complicating factor in the estimation of future energy demand is the likely rate and extent of urbanisation during, and by the end of, any of the periods for which forecasts might reasonably be attempted up to, say, 2025.

#### Urban-rural differences

Two things are immediately obvious to the visitor to Papua New Guinea; one is that the cities are high energy centres and that there are sharp differences in lifestyle between the Europeans and affluent Papua New Guineans and the large body of settlers in and around the cities. In 1976 Papua New Guinea's urban-industrial sector used roughly 70% of imported oil products excluding aviation fuels, though at this time urban dwellers were only 11% of the total



Figure 2a Papua New Guinea Fuel Imports, 1956-76

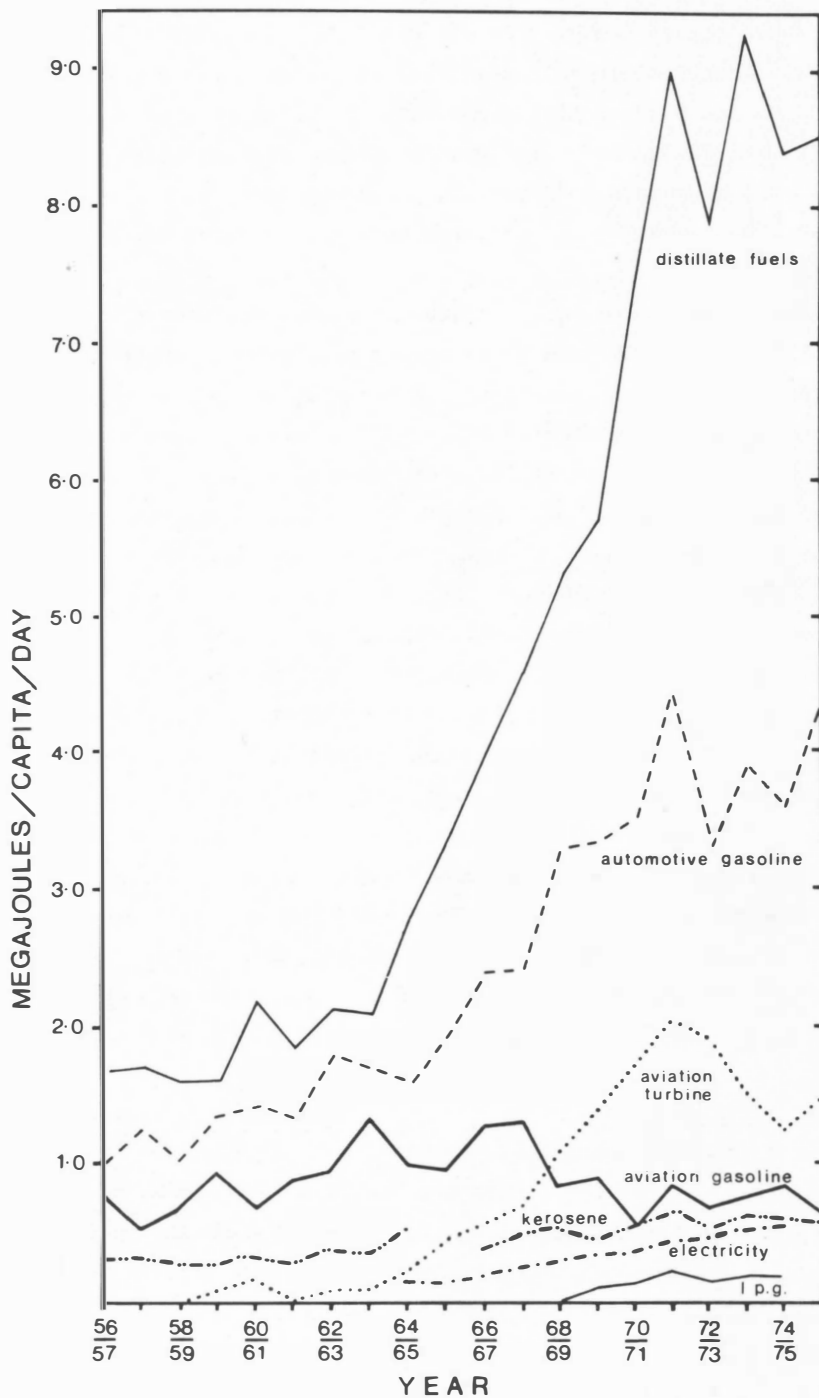


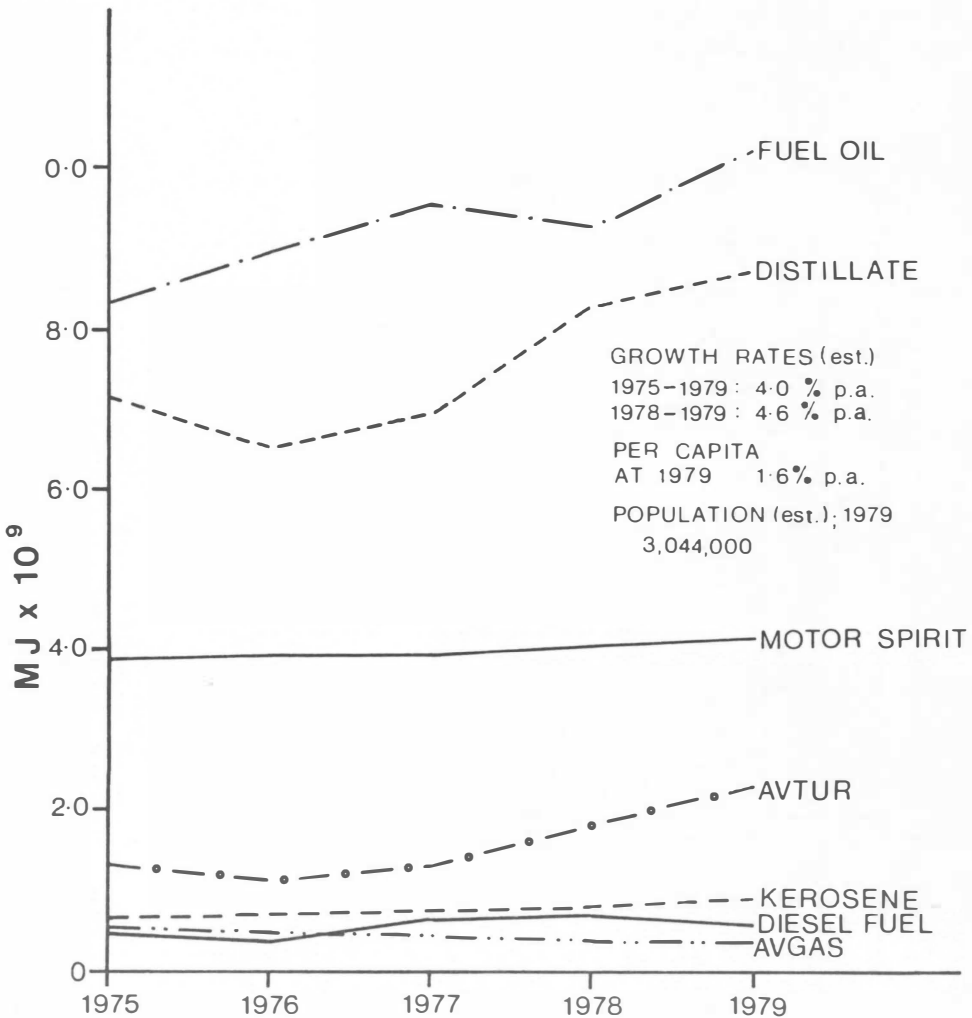
Table 3(a) Trends in Electricity Production and Imports of Petroleum Products, 1956-75

Year	Pop. (000's)	Liquefied Petroleum Gas (L.P.G.)		Aviation Gasoline		Automotive Gasoline		Aviation Turbine Fuel		Kerosene		Distillate Fuels		Electricity	
		MJ/Cap/Day	% Change	MJ/Cap/Day	% Change	MJ/Cap/Day	% Change	MJ/Cap/Day	% Change	MJ/Cap/Day	% Change	MJ/Cap/Day	% Change	MJ/Cap/Day	% Change
56/57	1748			0.74		1.00				0.29		1.61			
57/58	1768			0.53	-39	1.18	18			0.29	0	1.62	6		
58/59	1825			0.66	20	0.97	-22			0.27	-7	1.53	-5		
59/60	1855			0.88	25	1.27	24	0.07		0.26	-4	1.54	0.6		
60/61	1904			0.64	-37	1.34	5	0.17	250	0.32	19	2.07	26		
61/62	1972			0.83	23	1.27	-5	0.01	-1700	0.27	-18	1.76	-15		
62/63	2025			0.53	-57	1.70	25	0.07	700	0.37	27	2.02	15		
63/64	2059			1.28	59	1.59	-7	0.08	14	0.36	-2	2.00	-0.1	0.14	
64/65	2149			0.95	-35	1.51	-5	0.19	137	0.51	30	2.70	35	0.15	7
65/66	2185			0.91	-4	1.83	18	0.42	121	Error in Stats.		3.22	19	0.14	-7
66/67	2237			1.22	25	2.29	20	0.52	24	0.40		3.82	19	0.19	36
67/68	2292			1.25	2	2.30	1	0.67	29	0.48	17	4.40	15	0.24	26
68/69	2353			0.78	-40	3.13	27	1.03	55	0.49	2	5.07	15	0.29	21
69/70	2418	0.1		0.85	8	3.19	2	1.32	29	0.49	0	5.45	7	0.33	10
70/71	2490	0.12	20	0.53	-40	3.36	5	1.65	24	0.78	37	7.10	30	0.36	3
71/72	2552	0.21	70	0.78	32	4.22	20	1.95	18	0.63	-20	8.61	21	0.43	19
72/73	2620	0.13	-39	0.65	-20	3.14	-34	1.83	-4	0.49	-26	7.52	-13	0.46	7
73/74	2683	0.17	24	0.72	10	3.71	15	1.41	-23	0.59	17	8.89	17	0.48	4
74/75	2762	0.16	-6	0.82	12	3.44	-8	1.19	-16	0.56	-5	8.06	-9	0.51	6
75/76	2829			0.59	-39	4.20	18	1.40	18	0.53	-5	8.19	2		
Crude Ave. Growth Rate over Years Recorded:															
		2.8	10	-1.1		7.5		22		3.0		8.8		12	

Source: Trade Statistics, Papua New Guinea, 1956-76.

Table 3(b) Absolute increase in imported petroleum products

	<u>1956-76</u>					
	<u>(MJ x 10<sup>8</sup>)</u>					
	Avgas	Petrol	Avtur.	Kerosene	Distillate	Total
1956/57	4.72	6.38	-	1.85	10.27	23.22
1975/76	6.09	43.37	14.46	5.47	84.57	153.96
Absolute increase (multiple)	1.29	6.80	--	2.96	8.23	6.63

Figure 2(b) Trends in petroleum production, 1975-79

population. This estimation is generous with respect to the amount of distillate and petroleum fuels used by rural dwellers. The ratio of urban to rural per capita consumption of these imported energy forms is close to 20:1, in fact, 139MJ/capita/day to 7MJ/capita/day for rural dwellers including the major fuel oil consumer, BCL, in the urban-industrial sector.

The breakdown of petroleum fuels consumed per capita between rural and urban areas is given in Table 4. The difference in the use of all fuels between rural and urban areas is a clear indication of the urban bias in economic development reflected throughout the Third World (Lipton, 1976). This is not to infer that development which is successful in terms of Papua New Guinea's national development strategy will bring about an equivalence in rural and urban energy consumption. In developing countries, where agriculture is not heavily mechanised, and the rural to urban population ratio is the reverse of the developed countries, it is invariably true that urban dwellers consume more energy in per capita terms than rural dwellers. Balanced rural development can occur without a massive per capita increase in consumption of petroleum fuels, or of total energy inputs, but it will be hampered by excessive demand on foreign exchange caused by profligate use of imported fuels in urban areas, caused partly through the unchecked cultivation of high energy lifestyles. It is in this sense that Third World urbanisation planned, or left to evolve, along the western industrial lines adopted during the 1950's and 1960's, is a major threat to economic and social stability in developing countries in the decades ahead (see also Meier et al, 1978).

#### Energy flow through Lae: the commercial energy forms

Petroleum products are shipped into Lae in refined form from Singapore, South Korea, Bahrain and Australia. Singapore supplies 81% of total imported energy forms and South Korea and Australia 7% each. Figure 3 is a diagrammatic representation of the flow of petroleum products into and out of Lae. About 23% of Papua New Guinea's imported petroleum passes through oil company storage facilities, and out to coastal and highland centres of activity.

Table 4 Estimated Rural and Urban Consumption Levels of Imported Petroleum Fuels, 1975-76\*

Energy Form	Total Consumption			Per Capita Consumption**		
	Urban ( '000 Litres)	Rural	Total	Urban (MJ/Capita/Day)	Rural	Total
Distillate (diesel)	106,180	115,190	221,370	35.0	4.8	8.2
Petrol (benzine)	77,146	64,559	141,705	23.0	2.4	4.7
Kerosene	9,424	5,498	14,922	3.0	0.2	0.5
Liquefied Petroleum Gas	5,065	0.555	5,620	1.2	0.02	0.1
Fuel Oil	214,297	-	214,286	76.8	-	8.6
TOTALS	412,112	185,802	597,903	139.0	7.42	22.1
				(18.78 : 1)		

\* For this estimation Wau/Bulolo, Wewak, Rabaul, Port Moresby, Kieta-Arawa-Panguna, Mt. Hagen, Madang, Lae and Goroka were assumed to have per capita consumptions of these fuels similar to the Lae population average. These towns represent 75% of the urban population. The remaining 25% were assumed to have half of the Lae population average consumption for the fuels listed above. The use of fuel oil is limited to Lae, and Kieta-Arawa-Panguna.

\*\* Total population as of June, 1976 taken as 2,817,133, made up of urban 315,840 and rural 2,501,293.

Figure 3 Distribution Patterns of Petroleum Products to and from Lae, 1977

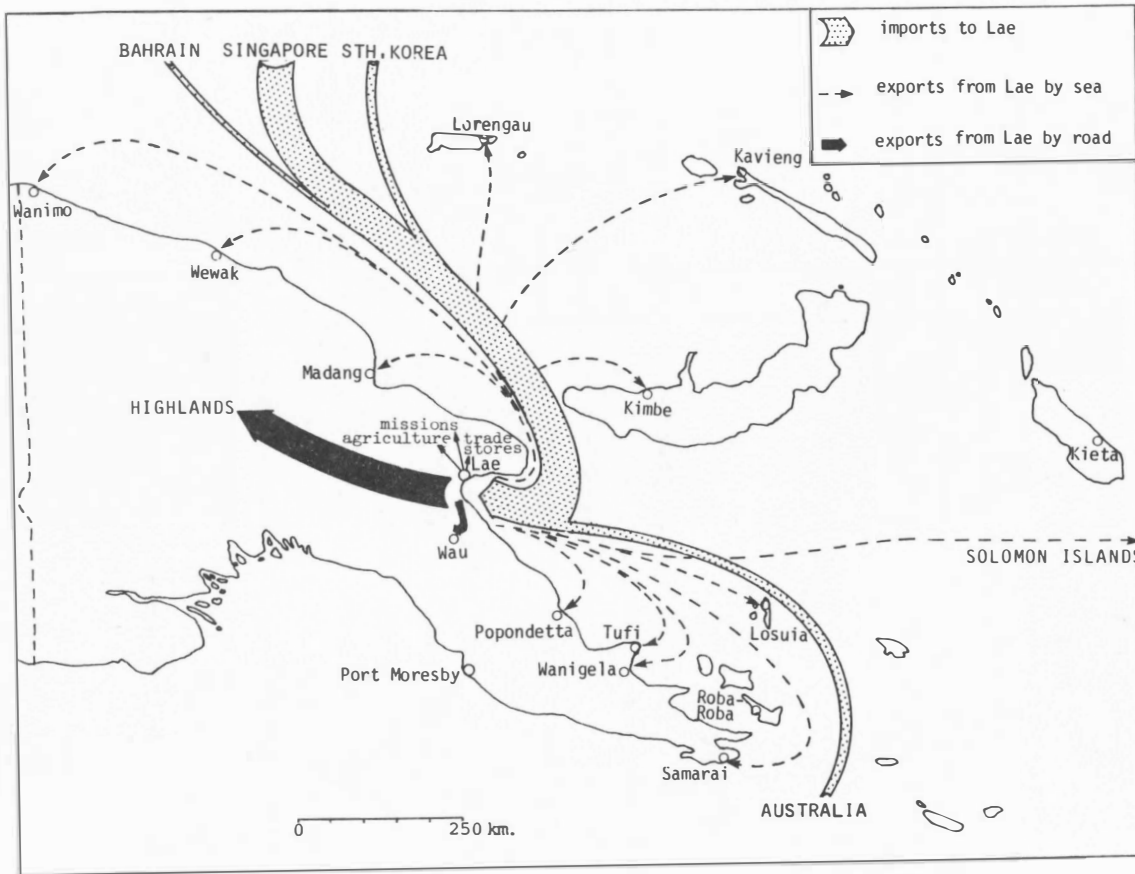


Table 5 shows that of the total input of fuels from overseas, 4% is re-exported to the Solomon Islands, 35% is shipped out to coastal ports and island communities, and 61% is trucked into the Highlands and Morobe Province by oil companies. Agents other than oil companies are responsible for distributing about 4% of the total input to Morobe Province and the Eastern Highlands. The details of distribution by agents other than oil companies are provided in Table 6. Those petroleum products which are retained for use in Lae represent about 10% of the country's total end-use of imported fuels.

The input and throughput of fuels to Lae is presented in detail in Tables 7a and 7b, and represented as a flow chart in Figure 4. The total of imports of commercial fuels excluding electricity is  $55,292 \times 10^5$  MJ, which is approaching 2,500 barrels of oil equivalent per day.

#### Sectoral end-use

The analytical approach that has proven most useful in the formulation of an alternative, or revised energy strategy, and which is adopted here and elsewhere in our work (Newcombe, 1975a and b), is known as the micro-sectoral approach. It is compatible with an ecological approach to an understanding of the behaviour of complex human ecosystems, and, indeed, has been recognised as the key to understanding the operation of natural plant and animal ecosystems for many decades (Cook, 1977). The basic contention is that since every action is enabled by an act of energy conversion, by tracing in detail the flow of energy through a society and documenting the quality and quantity at each end-use much is learnt about the behaviour and the critical relationships of the system, quite apart from the detail of energy use per se. The micro-sectoral approach brings the investigator into close contact with the major, and even minor energy users and thereby facilitates some understanding of the cultural context of present energy use, that is, the values, attitudes and preconceptions which have greatly influenced the selection of present energy forms, management and end-use technology. This level of 'information' about the system is essential to an evaluation of the rate at which apparently economic alternative sources,

Table 5 Import and Export of Petroleum Products,  
Lae, 1976-1977

(1) Origin of Fuels : To Lae

<u>Country</u>	<u>MJ x 10<sup>5</sup></u>	<u>Percentage of Total Fuel Imports</u>
Australia	3962.4	7
Singapore	44897.7	81
Bahrain	2760.2	5
Sth. Korea	3672.2	7
<u>Total</u>	<u>55292.5</u>	<u>100</u>

(2) Destination of Fuels : Out of Lae

<u>Mode</u>	<u>Destination</u>	<u>MJ x 10<sup>5</sup></u>	<u>% Mode</u>	<u>% Total Fuels</u>
Land	Highlands (Kaintantu, Goroka, Mt.Hagen, Kundiawa & Service Stations en route)			
	(a) Trade with energy companies	22211.98	93.4	
	(b) Morobe Province & Goroka, trade with other than energy companies (see Table 6)	1561.51	6.6	
	<u>Sub Total</u>	<u>23773.49</u>	<u>100.0</u>	<u>60.9</u>
Sea	Solomon Islands (re-export)	1727.5	11.3	
	Huon Gulf (Popendetta & Wau)	1101.0	6.7	
	PNG Ports (Wewak, Kavieng, Alotau, Kimbe, Lorengau, Samarai, Vanimo, Tufi, Doguna, Raba-Raba, Kulamadau, Losuia, Waniqela)	12497.6	82.0	
	<u>Sub Total</u>	<u>15326.1</u>	<u>100.0</u>	<u>39.1</u>



Table 6      Export of Fuels from Lae other than by Energy Companies  
(MJ x 10<sup>5</sup>)

Agent	Petrol	Distillate	Kerosene	L.P.G.	Aviation Gasoline	Total
Missions	26.70	44.87	39.84	5.42		116.83
Primary Industry	81.46	198.93	16.70	23.59		320.68
Wholesalers, Co-operatives & Trade Stores	190.85	306.89	138.00	10.04		645.78
Domestic use of building & road working contractors & loggers			32.29			32.29
Light aircraft operators					445.93	445.93
<b>Totals</b>	<b>299.01</b>	<b>550.69</b>	<b>226.83</b>	<b>39.05</b>	<b>445.93</b>	<b>1561.51</b>

TABLE 7 (a) INPUT AND THROUGHPUT OF COMMERCIAL ENERGY FORMS, LAE, JULY 1976 - JUNE 1977

ENERGY FORM	Imports		Re-Export by Energy Companies		Re-Export by other Agents		Retained for use Lae		Recorded use in Lae		Balance		Storage Capacity	
	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>	1x10 <sup>6</sup>	MJx10 <sup>5</sup>
PETROL	47.14	16165.74	35.43	12151.74	0.87	299.01	10.84	3714.99	11.02	3778.47	-0.18	-63.48	11.79	4044.14
DISTILLATE	74.42	28278.60	53.46	20313.72	1.45	550.69	19.51	7414.19	18.25	6936.50	1.26	477.69	18.53	7041.44
KEROSENE	9.21	3380.59	6.20	2281.83	0.62	226.83	2.39	871.93	1.50	549.50*	0.89	322.43	3.06	1122.57
FUEL OIL	5.44	2242.82	-	-	-	-	5.44	2242.82	5.40	2229.01	0.04	13.81	4.00	1533.40
AVIATION GASOLINE	7.10	2392.27	3.11	1049.42	1.32	445.93	2.67	896.92	2.98	1003.90	-0.31	-106.98		1132.13
AVIATION TURBINE FUEL	6.60	2402.40	4.36	1588.55	-	-	2.24	813.85	2.54	921.72	0.30	-107.87	4.00	1454.09
LIQUEFIED PETROLEUM GAS (L.P.G.)	1.65	430.03	0.24	62.75	0.15	39.05	1.26	328.23	1.25	327.11	0.01	1.12		N.A./N.K.
Sub-Total	151.56	55292.45	102.80	37448.01	4.41	1561.51	44.35	16282.93	42.94	15746.21		536.72		
	kWh'sx10 <sup>6</sup>						kWh'sx10 <sup>6</sup>				kWh'sx10 <sup>6</sup>			
ELECTRICITY	56.95	2122.03	-	-	-	-	58.95	2122.03		1982.88	54.91	139.15**		N.A.
TOTAL	151.56	57409.08	102.80	37448.01	4.17	1561.51		18496.57		17729.09		767.48		

\*of which an estimated 31.22 x 10<sup>5</sup> is used for cleaning

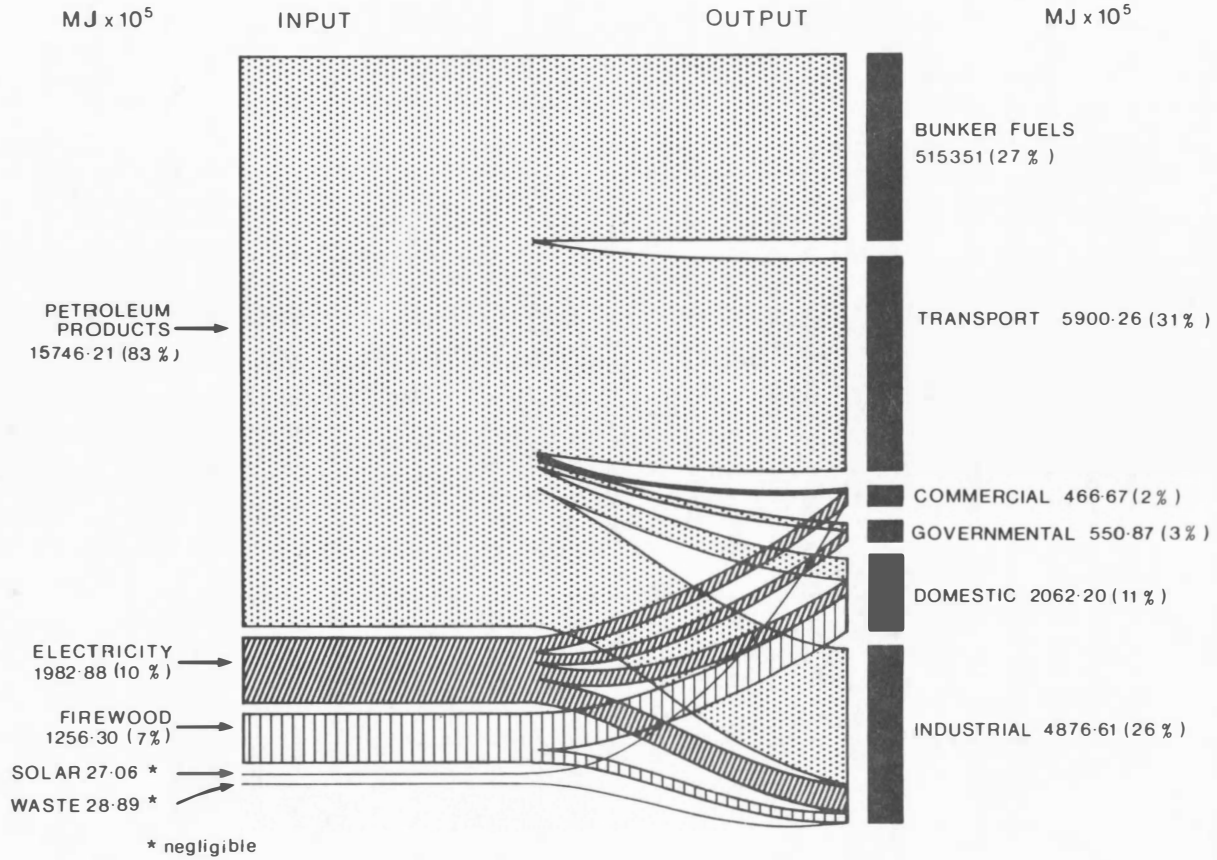
\*\* includes supplies to outside of urban Lae in Morobe Province such as Wau and Bulolo townships

Table 7(b) Energy use in Lae. Percentage breakdown  
by energy form

Energy Form	Breakdown (%)	
	Inc. Bunkers	Excl. Bunkers
Electricity	11.2	15.3
Distillate	36.7	27.6
Petrol	22.1	25.3
Kerosene	2.6	3.5
L.P.G.	1.8	2.5
Fuel Oil	12.6	17.2
Firewood	5.7	7.8
Solar	0.2	0.2
Avgas	2.2	0.2
Air turbine	4.9	0.3
	100	99.99*
Renewable/Non Renewable Ratio	1: 5.9	1: 4.3

\* Rounding errors

Figure 4 Energy Flow Chart for the City of Lae, 1977



and/or management practices can be introduced; in fact, the lack of this information is very often the reason why purely econometric approaches to energy demand forecasting and forward planning have failed.

Finally a micro-sectoral approach to the energy policy and planning process is well suited to the Third World, which, in comparison to the industrialised West, has few large and complex industrial-urban settings, and hence more human-scale settings; is much more reliant on non-commercial and hence infrequently recorded energy sources, and has much less capacity to mount highly sophisticated econometric models, requiring high level computerisation and specialised skill training.

In fact, wherever biomass fuels, such as firewood, charcoal, dung, rice hulls and so on are in use, there is no effective substitute for constant personal observation of the interactive effects of energy use and subsistence food production on economic and biological survival. In the industrial-commercial sectors, i.e. the modern 'sectors' and their related transport components, planners ought to be able to interact directly and regularly with the managers of the most energy-intensive activities. In the rapidly changing traditional sectors of domestic and agricultural energy use increasingly influenced by the market economy constant monitoring and feedback is required using well-established indicators of change in the stability or sustainability of current yields under present and higher demands. All of these data at the micro-scale have to be constantly reviewed and synthesised, to explain something of the direction of change, and the implications for biological and economic well-being for the population concerned. So this, then, must be the first step in energy planning; detailed analyses of thermodynamic quality and quantity of end-use at the micro-scale, within sectors, region by region, constantly revised so as to illuminate the key components of ecosystem form and function. From this base modelling of energy demands can profitably proceed, incorporating the game-playing, or simulation of energy price changes on the supply and demand of technically accessible energy forms.

This research into the direction and form of an energy policy for Papua New Guinea follows this general methodology. The detail of

energy-use in the major sectors of economic and energetic activity is presented in several policy papers, including the Industrial-Commercial, Transport and Domestic sectors (Newcombe, 1978, Newcombe et al, 1978, 1979). These data yield an overview of energy-use in Lae sector by sector, and fuel by fuel, which is presented in Table 8. From interpretation of these data for Lae, from additional data on national energy-use, and from an understanding of the major functions served by particular energy forms, an estimate is made in Tables 9 and 10 of the sectoral end-use of imported petroleum fuels, and of total energy use for Papua New Guinea as a whole. Private hydro-electric plants serving missions and other non-government institutions, and the use of solar radiation directly as a heat-source for crop drying, and water heating have not been included in this national overview, although their contribution is believed to be only a small percentage of total energy-use.

From Table 8 it is clear that transportation is the major energy using sector with 58% of total energy use, including bunker fuels, followed by industrial activities, 26%, domestic activities, 11%, government activities, 3%, and just over 2% in the commercial sector. Similarly, the most important source of energy is distillate fuels, split roughly in the ratio 4 to 1, between transportation and industrial fuel use. Petrol makes up 20% of total end-use, almost all of it in transportation. Electricity is 10% of total end-use with about 40% of it used in industry, and roughly equal portions of the remainder in other sectors. Electricity supply was 55GW hours in 1976-1977, equivalent to the supply from a 10MW facility at around 80% capacity. All but a negligible amount of this electricity was supplied by hydro-power from the Ramu River system.

Fuel oil provided about 12% of total energy-use, all within two industries; glass manufacturing and brewing. Firewood provided 7% of total energy use, 80% of which was used in the domestic sector and 20% in the industrial sector for steam raising in a sawmill. Kerosene use is nearly 3% of the total, being confined largely to domestic use in low-covenant housing in the urban settlements outside of the central business district on the urban fringe. LPG is a popular cooking fuel both in restaurants and high covenant expatriate homes, and represents 2% of total end-use. The only use of direct solar radiation, apart

TABLE 8 SECTORAL END-USE OF ENERGY IN LAE, 1976-77

(MJ x 10<sup>5</sup>)

SECTOR	COMMERCIAL	INDUSTRIAL	DOMESTIC	TRANSPORT	GOVERNMENT	TOTAL	PERCENTAGE OF END-USE BY ENERGY FORM
ENERGY FORM							
Electricity	382.68	768.05	445.24		386.91	1982.88	10.4
Distillate	29.06	1396.59		5391.08 <i>2351.45</i>	119.77	6936.50 <i>3896.87</i>	36.5
Petrol	10.01	31.39		3737.07 <i>3438.47</i>	- (212.98)	3778.47 <i>3479.87</i>	19.9
Kerosene	-	14.33	459.76		44.19	518.28*	2.7
Liquefied Petroleum Gas	44.58	148.05	134.48			327.11	1.7
Fuel Oil		2229.01				2229.01	11.7
Aviation Gasoline				1003.90 <i>66.10</i>	-	1003.90 <i>66.10</i>	5.3
Aviation Turbine Fuel				921.72 <i>44.24</i>	-	921.72 <i>44.24</i>	4.8
Firewood (10% Coffee Husks)		289.19	996.00			1285.19	6.8
Solar (Direct Radiation)	0.34		26.72			27.06	0.1
TOTAL	466.67	4876.61	2062.20	11053.77 <i>5900.26</i>	550.87	19010.12 <i>13856.61</i>	
PERCENTAGE of END-USE by SECTOR	2.5	25.7	10.8	58.1 (incl.bunker)	2.9		100.0

\*Differs from Table 7 because of subtraction of kerosene for cleaning in industry.

Note: The figures in brackets represent the end-use of energy in that sector if transport fuels used in that sector are included there rather than in the transport sector.

The figures in *italics* are those applying if bunker fuels are excluded. Bunker fuels here include 95% of petrol, diesel, aviation gasoline and aviation turbine used for long-distance haulage, earthmoving and road construction, shipping and all aircraft operations.

Table 9 Sectoral End-use of Imported Petroleum Fuels  
1976-77

(Percentage)

Energy Form	Transport	Industry-Commerce	Domestic	Total
Petrol (1)	17.6	0.2		17.8
Aviation Fuels	8.5			8.5
Fuel Oil (2)	0.7	1.5		2.2
- For Electricity (3)		33.2	1.0	34.2
Diesel (4)	24.8	6.2		31.0
- For Electricity (5)		1.7	1.7	3.4
LPG (6)		0.4	0.3	0.7
Kerosene (7)		0.4	1.8	2.2
	51.6	43.6	4.8	100.0

Footnotes:

- (1) About 1% of petrol imports is used for small stationary motors in industry.
- (2) 94% of fuel oil imports go to Bougainville Copper Limited. The remainder goes into other industry end-uses and bunkering at a ratio of about 70-30 respectively.
- (3) Electricity generated at BCL is 95% for mining, almost 3% for domestic purposes, and 2% for commerce.
- (4) About 90% of diesel imports are for industrial and transport end-uses, and 10% for electricity operation. The industrial and transport end-uses are split 80% to transport and 20% to industry. Of the transportation sector 80% is on land, and 20% on sea.
- (5) Generation is assumed to be split 50:50 between domestic and commercial industrial end-uses.
- (6) LPG use is about 40% domestic, 60% industrial and commercial.
- (7) Kerosene use is about 80% domestic and 20% industrial.



Table 10      Estimated Sectoral End-use of Energy, PNG,  
1975-76

	<u>Commercial</u>	<u>Industrial</u>	<u>Domestic</u>	<u>Transport</u>	<u>Total</u>
	(MJ x 10 <sup>8</sup> )				
Electricity	2.76	27.48	3.81		34.05
Distillate		19.56		55.98	75.54
Petrol		0.15		43.02	43.17
Kerosene		0.55	4.93		5.48
Liquefied Petroleum Gas	0.37	0.36	0.74		1.47
Fuel Oil		5.31			5.31
Aviation Gasoline				6.07	6.07
Aviation Turbine Fuel				14.62	14.62
Firewood		16.11	144.99		<u>161.10</u>
Totals	3.13	69.52	154.47	119.69	<u>346.81</u>
Sectoral End-use %	0.9	20.0	44.6	34.5	100.0

Source: This paper on Lae provides some estimates of overall splits in energy, and is supplemented by the following; for electricity personal communication, I. Namake, Papua New Guinea Electricity Commission, personal communication, Bougainville Copper Limited; for firewood Newcombe et al (1979), Hipsley et al, (1965); for petroleum products personal communication, Shell Oil, and Mobil Oil Companies. Deductions can be made on the basis of Import data to mainports Papua New Guinea, Bureau of Statistics, personal communication 1977.

from drying clothes, was through 189 collectors installed for hot water in homes, and one for hot water in industry at that time.

The distribution of these energy forms in Lae sector by sector, and the sectoral end-use of energy is illustrated in Figure 4. Of total petroleum imports, about 52% is used in transportation, 44% in industry and commerce and 5% in households (see Table 9). The use of fuel oil at Bougainville Copper Limited is 34% of total petroleum imports, all of which is used to generate electricity. The replacement of fuel oil here with renewable energy sources is a high priority in future energy development, but prospects of replacing part by hydro-power (65% would be replaced by the Luluia hydro-electricity scheme) are poor because of uncertainties about the mine's life. Alternative boiler fuels - pyrolytic char in particular - will not be economic for this application for perhaps 5 years, and by then there may not be time to warrant the new plant, and/or boiler modifications that will be necessary to utilise them. The pyrolytic fuels option is, however, the most flexible of the two in strategic terms.

Transport fuels are used mostly in road vehicles (37% total imports), which, including BCL's fuel oil, use 52% of imported petroleum products, making alternative transport fuels a prime target for import substitution. In order of importance in respect of fuel volumes we have the difficult task of finding alternative aviation fuels then alternatives to diesel generated electricity, and alternative fuels for coastal shipping. Even here there is promise as photovoltaic cells now appear competitive with diesel generation for outlying areas (L. Weick, Department of Minerals and Energy, pers. comm., 1979), and alcohol fuels and plant oils could substitute for petroleum fuels for coastal shipping.

The sectoral end-use of energy in Papua New Guinea for 1975-1976 is estimated in Table 10 from a number of complementary data sources, including the Lae study. Nevertheless the overview is an approximation, and a much more precise picture, essential to local energy planning, will have to await the processing of the national energy census data being collected annually from 1979 onwards. The influence of the so-called 'non-commercial' energy form of wood is significant on the sectoral end-use pattern, making households the largest energy-using sector with 45% of the total, directing our attention again to the

relative importance of village energy supplies and away from the potential pre-occupation with imported petroleum and 'modern' sector activities.

Transportation uses 35% of national energy supplies, industry uses 20% and commercial activities a mere 1%. Although the precise pattern of end-use across the towns and villages of Papua New Guinea is unique to each local setting, the detailed data for Lae, and the Simbu Province contained in the other energy policy papers in this series provide a reasonably accurate description of the general situation, and hence the problems, and possible solutions, faced at the national level.

#### Trends in National energy use

In discussing the modern, or so-called commercial energy forms trends were shown in the use of petroleum fuels over the 1956-75 period. At Independence, in 1975, the substantial effort invested in data collection by the Australian Bureau of Statistics for the former Territory of Papua New Guinea ceased, and since then no complete data on energy imports are available, except by piecing together oil company records. This lack of continuity in energy import data is serious, for it will be 1980 before such data is available again. In the interim there is reason to believe that great changes have taken place in per capita energy consumption. In 1972 just after the first indications that there would be an independent Papua New Guinea in the short term, many thousands of expatriates left Papua New Guinea and, consequently, significant changes in the consumption of imported petroleum products occurred (see Figure 2). Again, after the oil crisis in 1973-74, a marked hesitation occurred in per capita demand for petroleum products. Following this period, i.e. 1974-76, the growth of consumption of petroleum products was half that of the average for the previous decade, and was quite unsteady. This 2 year period is a poor indicator of the trends that followed until the present, and only now, as a result of this study can some indicative data be gleaned of the present level of per capita consumption.

Despite this paucity of recent data some forecast must be made of future energy demand for forward planning purposes. The effort that is made here to predict future energy demand for Papua New Guinea

to the year 2000 is, then, necessarily simplified, and must be regarded with its shortcomings firmly in mind.

The following description of the methodology should reveal the assumptions made and provide an understanding of the key variables influencing energy growth. The most obvious characteristic of the forecast demands is that consumption grows exponentially for the period under consideration, simply because population growth and per capita energy growth are regarded as constant and unperturbed. The only difference in results stems from choosing different growth rates in per capita energy-use for each of the scenarios selected.

#### Scenario preparation

It is clear that in respect of imported petroleum products a major influence on per capita consumption is the growth of the urban-industrial sector, and especially of the transportation serving it. Another major factor is, as always, population growth. The combined effects of these variables in the 1950-74 period was to cause a seven-fold increase in the absolute amount of petroleum products imported. Even so the level of per capita consumption at the end of that period was only two-thirds of the average for the developing countries as a whole (U.N. definition, U.N., 1976). Since in 1976, only 11% of the population was urbanised, and the growth rate of the urban population was at least three times that of the rural population, the energy intensity, or for the time being, the oil intensity of Papua New Guinea's life styles is bound to increase significantly. Also, the population growth for all of Papua New Guinea averages about 2.85% per annum - high by any standards, and a strong driving force on energy demand.

To illustrate the potential range of demands for imported energy, three scenarios have been adopted:

- i) No growth: No increase in the per capita consumption beyond the average levels of 1976, standing at 24MJ/capita (0.29kW) for commercial fuels, and 16MJ (0.19kW) for firewood. Only population growth will drive demand.
- ii) Slow growth: 3% growth in per capita energy demand, following the post-oil crisis trend, and in line with slow, but steady

economic growth.

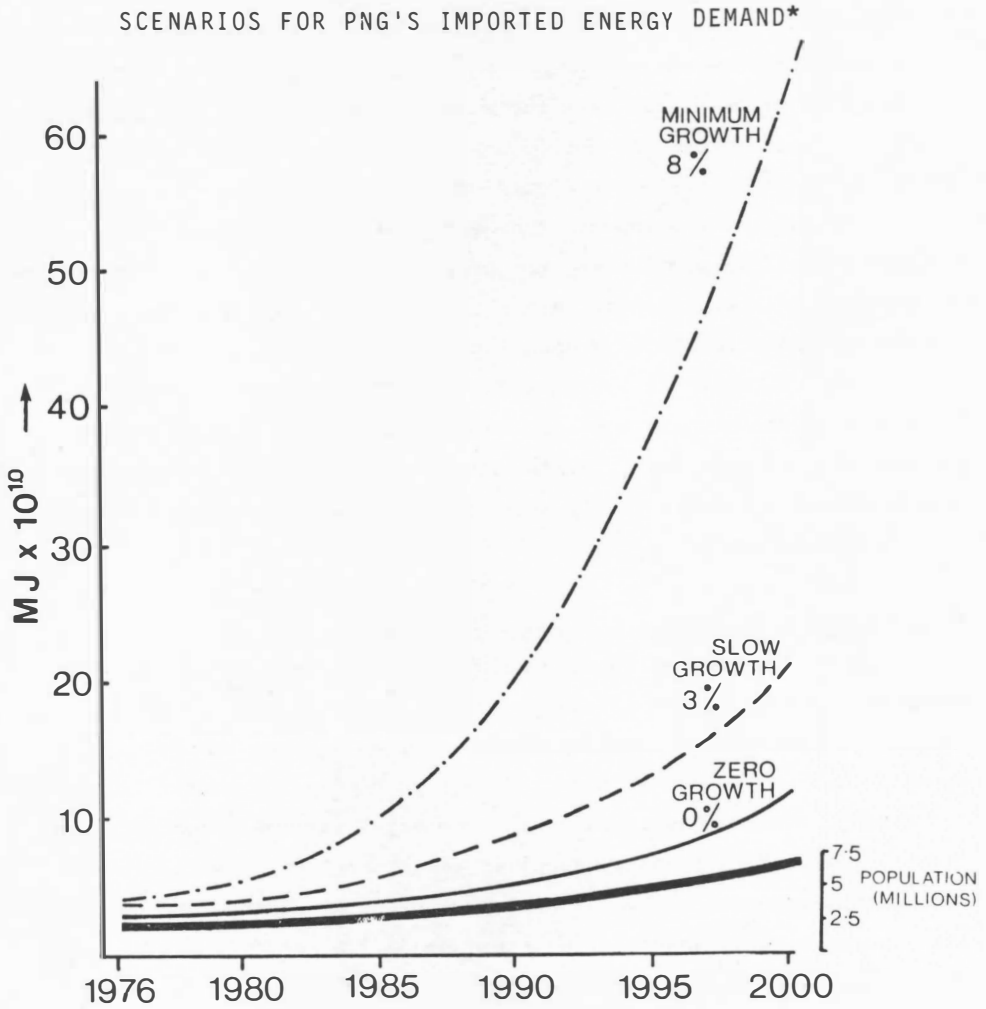
- iii) Maximum growth: 8% growth in per capita demand; paralleling average demand for the last decade in Papua New Guinea, and similar to growth in demand for imported oil in the Asian-South Pacific region in the 1960-73 period (ESCAP, 1973).

To calculate demand for the period 1976-2000, estimates were made of the urban and rural population until 2000, based on a 7.5% per annum growth in the urban population, and a 2.5% growth in the rural population using the 1971 census data as a base (Bureau of Statistics, pers. comm., 1978). At the time of compiling these data the Bureau of Statistics had not completed population forecasts to 1986, but estimates used here, derived from the above, yield urban, rural, and total population figures for 1976-81 and 86 only 0.9% higher than subsequently available Bureau of Statistics forecasts. (J. Shadlow, Bureau of Statistics, pers. comm., 1978).

The Lae data provided per capita estimates for the urban population, which for motor spirit and distillate, were taken as indicative of 9 major urban areas, constituting 75% of the urban population. The remaining 25% were regarded as having half the Lae average per capita consumption for these energy forms. Kerosene and LPG were taken at the Lae average for all urban areas. Fuel oil was treated separately as 94% of the 1976 demand was for power generation at Bougainville Copper, assumed to be a fixed demand for the period. Hence, only the minor demand in Lae, and Port Moresby, for industrial use and bunker fuels was escalated in each scenario. Aviation fuels were not assigned an urban-rural differential, but were escalated from their overall average per capita usage at 1976.

The results of these manipulations are shown in Figure 5(a) in very simple form. By the year 2000, under the 'maximum growth' scenario, petroleum imports rise by 15-fold; under the 'slow growth' scenario by 5-fold, and even under the 'no growth' scenario by 2-3 fold. It is already obvious that the 'no-growth' scenario is unrealistic; per capita energy consumption is rising at least at the 3% level. While the Papua New Guinea economy is not buoyant, neither is it floundering. Inflation is 5-10% lower than most trading partners, and growth is steady. Quite simply, then, over the past 20 years,

Figure 5(a)



\*NOTE: FROM FIGURE 2(b) IT IS CLEAR THAT THE 1975-1979 GROWTH-RATE IS MID-WAY BETWEEN THE ZERO GROWTH AND THE SLOW GROWTH SCENARIOS.

the demand for imported petroleum products would rise perhaps five-fold, even higher, if unhindered by relative price rises for energy globally, or economic disruption for other reasons globally or locally.

To complete the picture of national trends, the sectoral end-use patterns which emerge from the most likely, or slow growth scenario, of 3% per capita growth in energy use to the year 2000 are presented in Table 11, and illustrated in Figure 5(b).

Because of the impact of urbanisation on the demand for transport fuels in particular, the proportion of total energy use which is utilised by the transport sector increases greatly over the period. These data indicate almost a doubling in the share of end-use by transportation, which is anticipated to shift from 34.5% to 60.4% of total energy use between now and the year 2000. The importance of this trend for Papua New Guinea's development is obvious because the global energy crisis is really a crisis in the supply of liquid fuels for transportation.

#### The need for alternatives

The scenarios of future energy demand illustrated above have shown one element of the matrix clearly; Papua New Guinea's demand for imported petroleum products is rapidly increasing when the global capacity and motivation of oil producers to supply the market is rapidly decreasing. This tells it all; the economic, strategic and political needs for alternative energy supplies all arise from this fairly well supported estimation of Papua New Guinea's energy future, and the recent past in Papua New Guinea affirms these needs just as forcibly as does any speculation about events to come.

Between 1971 and 1977 the cost to Papua New Guinea of energy as a proportion of total imports rose four-fold, from 2.5% to in excess of 10%, with no sign of abatement, and during the 1971-1978 period the price of petrol and kerosene rose 1.5 times faster than the price of the basket of goods used to calculate the consumer price index (Newcombe and Weick, 1978). A simple projection of these trends estimates very real economic pressure in the early 1980's, although in terms of the government's development strategy this is already being felt. From 1974 the government introduced a subsidy for rural people

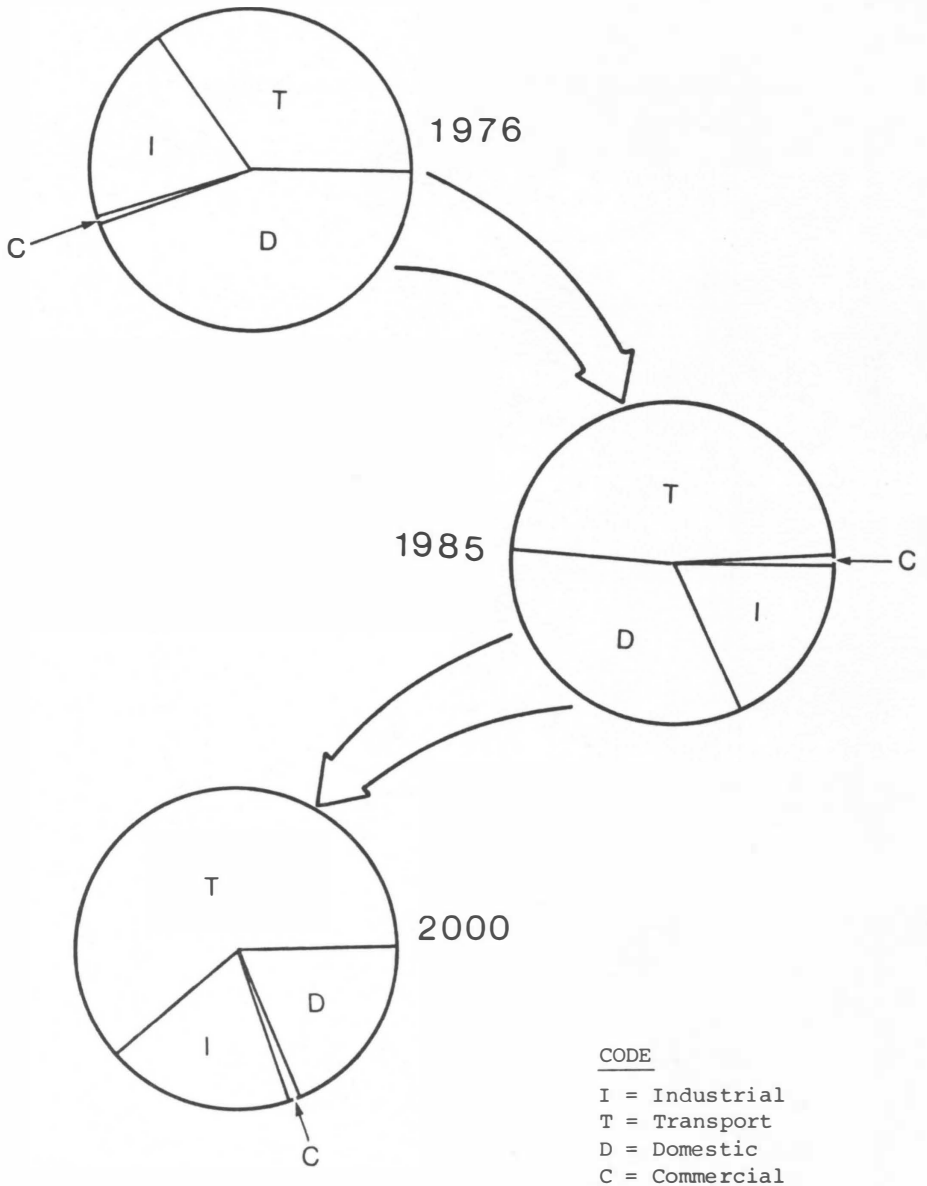
Table 11      Overall Sectoral End-use Trends,  
Papua New Guinea

1976-2000 (3% Growth Scenario)

Year	(%)				%	Total (MJ x 10 <sup>8</sup> )
	Industrial	Commercial	Domestic	Transport		
1976	20.0	0.9	44.6	34.5	100.0	346.81
1985	18.0	1.0	33.6	47.4	100.0	583.5
2000	16.9	1.0	21.7	60.4	100.0	1537.0



Figure 5(b) Overall Sectoral End-use Trends, Papua New Guinea  
1976-2000 (see Table 11)



for the purchase of distillate, motor spirit and kerosene. This subsidy was available when prices for these fuels, because of distribution costs, reached 20t/gallon above the main port prices. This level of subsidy was maintained until 1978 up until which time the overall payouts to retailers and major consumers grew at 27.5% per annum and reached Kl.3M. At that time the subsidy was shifted to apply only when prices exceeded 30t/gallon above main port prices and again Kl.3M was budgeted for subsidisation during 1979. For a development plan emphasising rural development in balance with growth in the urban-industrial sector, and reliance on stable subsistence agriculture in addition to the export of cash crops from the rural hinterland, the post oil-crisis era has already brought a taste of things to come if dependency on imported petroleum is to be maintained.

These scant details of the impact of the oil crisis on Papua New Guinea fit well the general picture of oil-importing developing countries (OIDC's) in recent years. As Powelson (1978) describes it, this era has left this particular group of countries worse off than all others. Between 1970 and 1975 they have suffered a net increase in this collective debt of 17 billion dollars (US) due to the increase cost of oil imports alone. Whereas Western Europe and the United States of America were more oil dependent, they managed to recycle much of the petro-dollars into their economies, by having them handled by their banking institutions, and spent on their goods and services. Despite promises by OPEC to protect OIDC's, relief through aid has been miniscule and directed, when available, to 'kinship' affiliates.

Forecasts of price rises are, as can be expected, many and varied. The CIA (1977) can be regarded as the pessimists, predicting sharp price rises in 1982-83 in expectation of OPEC's inability to meet the growing world oil demand by 1985. Statements by Sheik Yamani reinforce the CIA case (Reuters, August 21, 1978), by emphasising that Saudi Arabia has no intention of developing its capacity beyond 14MBd by 1985, when 19-23MBd is believed by the CIA to be the minimum the Saudi's must achieve for OPEC to meet world demand. The Saudis are the major producers, now supplying 30% of OPEC oil, hence its policies are of crucial importance. It is currently producing 9.5MBd. On the other hand projections made by a number

of commentators do not predict significant price rises until the early 1990's (see Ulph, 1978). Occupying the middle ground, though not by intention, is a recent thorough integrative study which investigates the multitude of factors effecting supply and demand and predicts sharp price rises in the late 1980's (Steinberge and Yagar, 1977).

These projections predate the 14.5% price-hike for 1979 announced by OPEC in November 1978 and topped up by a further 9% in April 1978, leading to an effective 25% increase by the end of 1979\*. Of course, the other factor in the supply of oil globally is its 'political security'. While King Hubbert and others anticipated, from a hard geological data base, the downturn in global oil supply, the 1973-74 oil crisis was a politically motivated event. It is interesting, then, that the above predictions of future oil supply, and therefore oil prices, also predate the Iranian crisis. Iran was the second biggest OPEC oil producer in March 1977 contributing 25% of OPEC supply, or 6.7MBd. In the first quarter of 1979 its production was negligible, and is not expected to rise above 3MBd in the foreseeable future.

In summary, the integration of known economic facts, and development impacts, in the recent past in Papua New Guinea, with those provided above in respect of the economic and strategic future of oil supply and demand, yield compelling reasons why Papua New Guinea, as an OICD with a rapidly increasing petroleum demand, should seek to establish locally available renewable energy sources and management programmes for improved energy efficiency. From the Papua New Guinea Government's viewpoint it is comforting, then, that alternatives appear to be many, and opportunities for their early exploitation, under economically and strategically favourable circumstances, appear to be abundant.

#### The potential shift to renewable energy sources for Lae

A brief summary is presented here of the potential shift across to locally available renewable energy sources in Lae during the years leading up to 2000. The question of self-sufficiency in renewable energy sources for Lae has been addressed in detail in each of the sector policy papers of this series (Newcombe, 1978; Newcombe et al, 1978). In Table 12 is presented an analysis of the overall potential

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\*Actual oil price rises amounted to 60-100% by first quarter 1980, depending on the product.

Table 12 Proportion of Total Energy Demand which can be derived from Renewable Energy Sources, Lae, 1977-2000

Sectors	1977				1985				2000			
	Total Energy-use (MJ x 10 <sup>8</sup> )	Sectoral end-use %	Proportion from Renewable Sources %	Renewable Energy Sources (MJ x 10 <sup>8</sup> )	Total Energy-use (MJ x 10 <sup>8</sup> )	Sectoral end-use %	Proportion from Renewable Sources %	Renewable Energy Sources (MJ x 10 <sup>8</sup> )	Total Energy-use (MJ x 10 <sup>8</sup> )	Sectoral end-use %	Proportion from Renewable Sources %	Renewable Energy Sources (MJ x 10 <sup>8</sup> )
Domestic(1)	2.06	11	71	1.46	3.56	11	77	2.74	9.96	10	80-100	7.97-9.96
Industrial-Commercial(2)	5.90	31	31	1.83	8.70	27	85	7.40	18.09	19	100	18.00
Transport(3)	11.05	58	0	0	20.84	62	17	3.46	67.55	71	27-83	18.24-56.07
<b>TOTALS</b>	<b>19.01</b>		<b>17</b>	<b>3.29</b>	<b>32.60</b>		<b>42</b>	<b>13.60</b>	<b>95.60</b>		<b>46-88</b>	<b>44.30-84.12</b>

(1) Future energy-use is determined by calculating the product of 2% p.a. growth in per capita energy use and 5% p.a. growth in population.

(2) Includes government sector. Future energy use is determined by calculating a 5% p.a. growth in total energy use.

(3) Future energy use is the product of 3% p.a. per capita growth in energy use and 5% p.a. growth in population. Aviation fuels are included but no alternative is expected to be found for them by 2000.

SOURCE: Table 8, Newcombe, 1978; Newcombe et al, 1978.

for a further increase in the use of renewable energy sources under specified patterns of growth in total energy use, using sector by sector differences in anticipated growth in energy-use compatible with a 'best guess' based on the detail of present energy-use in Lae within each sector. The data presented indicate that 17% of the 1977 energy-use in Lae was from renewable energy sources, though none of the transport energy was from such sources. On the other hand, 71% of domestic energy, being firewood and electricity, and 31% of industrial-commercial energy, being electricity, firewood and wastes, were from renewable energy sources.

In order to evaluate the estimates of renewable energy sources (RES) as a proportion of future demand it is worth noting the anticipated shift in sectoral end-use, and the scenario of growth in energy-use for Lae detailed in Table 12. Industry in Lae is not anticipated to become significantly more energy intensive and overall energy-use in this sector is not seen as strongly related to the growth of population in Lae during this period. However, transportation is seen as strongly related to population growth because of the demand for movement around town and between Lae and its hinterland. Similarly, with improved highway conditions upon extensive road sealing now underway, the flow of traffic linking Lae with its hinterland is likely to expand rapidly, and Lae will act as a bunker supply depot for a significant proportion of this transport energy. Domestic consumption is estimated to increase at 2% per capita, slightly above the national urban average under the 'slow growth' scenario for national energy use. This combined with a 5% p.a. growth in the Lae population estimated by the Bureau of Statistics, Papua New Guinea, provides the basis for future domestic energy demand. The low per capita growth rate is chosen because there are at present lower levels of energy-use per capita amongst middle level urban Papua New Guineans than amongst the settlement dwellers. This difference is related to the thermodynamic quality of the energy used for cooking, and to improvements in both first and second law efficiencies in the middle income, low-covenant housing dwellers' energy use where hydro-electric power is used for lighting, and kerosene and wood stoves are used more often than open fires. Hence, even though the actual

work achieved in low-covenant households is higher than for self-help settlers, absolute energy-use is lower in per capita terms.

Bearing these assumptions and observations in mind the future energy demand is estimated, and the proportion to be expected to be derived from RES is calculated in Table 12. By 1985, 75% of domestic, 22% of industrial-commercial and 17% of transport energy is expected to be from RES, and this is expected to rise to a lower estimate of 80%, 100% and 27% from RES, respectively, for these sectors by 2000. These sectoral data yield overall RES contributions of 42% in 1985 and 46% to 88% in 2000. Indeed, only the lack of an alternative aviation fuel presents a barrier to complete energy self-sufficiency for Lae for the year 2000. Suffice it to remark here that the presumed technical and economic capability to achieve such a high level of energy self-sufficiency says nothing of the political and administrative difficulties to be overcome in achieving this objective.

#### The sources of renewable energy for Lae

The alternative energy sources for Lae are dealt with in detail in each of the sector papers, and these are the origins of the summary data in Table 12. It is nevertheless of value to briefly refer to these sources here.

For transportation ethanol is the only major alternative foreseen, although biogas is expected to power fleet vehicles for the Lae City Council in 1980. Ethanol is believed to come first from broadacre farming for Cassava, either alone or in combination with sugarcane. If the proposed sugar industry goes ahead alcohol will be available from fermentation of molasses. These sources will provide a minimum of 2.5Ml by 1985, and possible 12Ml or more. By 1995 wood-waste to ethanol will be economically feasible as will expanded cassava production, and or fuelwood cropping, possibly of Leucena sp., providing a minimum of 64Ml, and possibly all but aviation fuels, as pure alcohol fuel motors are available. From mid-1980 right-hand drive alcohol fueled vehicles will be available in a wide range of size and performance from Brazil, especially Volkswagen Brazil (Newcombe et al, 1980). Three vehicles from VW Brazil with alcohol fueled motors - all of them VWB micro-buses - are being purchased as demonstration vehicles from Brazil in 1980.

For industry 85% of the 0.79GJ of anticipated demand can be met by pyrolytic fuels from pyrolysis of wood waste, the use of industrial waste such as paper, cardboard and coffee husks, and by hydropower, if, for heat-raising, the existing industrial-commercial users switch over their energy equipment to enable char combustion by that time. No barrier is foreseen to complete conversion to dual-fuel systems by 2000, and wood waste, forest residues and hydro-power are in adequate supply to meet demand at that time (Newcombe, 1978).

Domestic energy use is already heavily reliant on renewable energy sources, in the form of hydro-power and firewood. Comment will be made on what constitutes a truly renewable energy source in this context later, for without proper management both these sources could easily become non-renewable. It is envisaged that firewood supplies be stabilised; that efficiency of cooking can increase by conversion to charcoal; that kerosene substitutes in the form of ethanol or methanol can be found for lighting, and hydro-power, or autonomous photovoltaic cell packages be extended and developed to cater entirely for the domestic demand by 2000. LPG is expected to be pushed out of the domestic market by that time (Newcombe, 1979).

Following on from this initial research work three feasibility studies on the production of alcohol fuels from cassava, sugarcane and Sago palm are now underway, and construction has begun on a 2Ml/year cassava-ethanol plant at the Baiyer River in the Western Highlands of Papua New Guinea. A 3 ODT/day pilot pyrolytic fuels plant has been completed and a 25 ODT/day plant is under design for construction by late 1980 in Lae. A firewood distribution programme using wood waste from Lae's sawmill has been implemented and a firewood cropping programme has been initiated as part of an ecologically sustainable agro-forestry rehabilitation of the Atzera Ranges contiguous with the low-income settlements of Lae (Newcombe, 1979, a & b). All of these projects have been funded and implemented by national and local government, mostly through the 1979 National Public Expenditure Plan (NPO, 1978).

#### Renewable energy potential at the national level

This section will merely present an overview of the kind and status of significant renewable sources that can be developed economically before the year 2000. An overview of a more comprehensive nature

of Papua New Guinea's energy options is provided in Newcombe and Weick (1978), partially revised in the subsequent government White Paper on energy policy and planning (Energy Planning Unit, 1979). The data presented here in respect of selected resources represent a further revision and expansion of those contained in the latter document.

It is obvious that this section must be severely limited by the information that is available, not only about the status of physical resources, but about the technological, economic and ecological context in which they might be exploited. In all cases we are ultimately talking about solar energy, regardless of whether we are referring to hydro-power or forest resources, for they are all forms of harvesting solar energy. First, the deficiencies; there is no estimate of the extensive geothermal resource which exists in Papua New Guinea, although the geological survey section of government is conducting some fieldwork into the potential here. Secondly, only the crudest estimates are available of the hydro-power potential of Papua New Guinea, and this is a very serious deficiency since the resource has already been developed to some extent, and the detailed ranking of sites in terms of their hydrological and economic potential is an essential component of forward planning for further exploitation. Finally, the forest energy resources reported here, with the partial exception of forest and sawmill residues, are incompletely surveyed, and in some instances the product of 'educated guesswork' on the basis of aerial photography and local familiarity with the environment.

#### 1. Hydro-power

From fairly cursory fieldwork in 1971, the Australian Department of Housing and Construction estimated the hydro-power resource of Papua New Guinea at 14,000MW, at 80% load factor, 56% of which was in the Purari Basin, 26% in the adjoining Kikori Basin, and 11% in the Strickland River Basin (ADHC, 1974). This survey did not consider in this total any resource likely to be less than 50MW, and in excess of A\$600 (1971 dollars)/kW to install. They found a number of river basins including one now being seriously investigated, the Vanapa, as



yielding power in excess of 50MW, but excluded them on a cost basis.

This survey was without doubt a thumbnail sketch of the resource potential, and not anything like the comprehensive research which is now warranted. Most of the important parameters, such as head and river flow were estimated from helicopter surveillance, aerial photography and rainfall isohyets. Basic development costing was also crude, as geological data for civil engineering costs were usually not available. It is also arguable that Papua New Guinea ought to be concerned only to prove up hydro resources in excess of 50MW when the majority of its internal power requirements are met from individual units of supply considerably less than this. In other words micro-hydro is probably a more important resource for Papua New Guinea than major hydro schemes at this point in its development.

The ADHC (1974) data indicate a yield of  $4415 \times 10^8$  MJ, about three times the energy requirements for Papua New Guinea by the year 2000 under our 'slow growth scenario'. More to the point, the demand for electricity at 2000 is estimated under this scenario to be only 1.7% of this resource, provided there is no development of electricity from the Purari Basin for export, or for exclusive use by one or two huge industries in the Papuan Gulf Provinces.

It is obvious, then, that the utilisation of this hydro-resource this century will be minimal. To date only 94 MW have been tapped, and a further total of 200 MW are under serious consideration by the Electricity Commission and the Department of Minerals and Energy for installation by 1990. In other words, by 1990 only 2.1% of the resource potential may have been tapped. It is unlikely that more than an additional 100 MW will have been brought into use by 2000, assuming, of course, that the 1800 MW first stage of the Purari project has not been developed by that time. There are no firm plans for Purari development now which means that the early 1990's is the earliest that this scheme could be operative.

Quite apart from the likely utilisation factor of Papua New Guinea's hydro-resource this century, there are serious questions of the compatibility of large-scale hydro-power development and extensive transmission, with the national development strategy, especially as other localised sources of electricity, such as wood-fired, producer-gas, and mini and micro-hydro power became available

at similar cost. Plans have now been prepared for the establishment of a K3.5 million rolling fund for micro-hydro development to displace diesel generation, and for an extensive evaluation and ranking of the hydro-power resource in the range 5-25 MW or thereabouts. The 'rolling fund' is designed to alleviate the first costs of hydro-power development, so far a barrier to utilisation of this resource.

## 2. Biomass resources

Included here are the wastes from existing forestry operations which can be expected to be available at the current level or above indefinitely, and naturally occurring stands of trees which offer considerable potential as a renewable energy source. Energy farming of forests has long been implicit in the swidden cultivation mode of indigenous agriculturalists. Their management of the forest resource as part of an agro-forestry complex provided, in most areas, a sustainable yield of both food and firewood energy. In other areas, such as the Markham Valley and the Eastern Highlands patterns of exploitation were not compatible with long term sustainable yields and Kunai grasslands are rapidly taking over from forest cover. The only explicit energy farming of forests is the firewood cropping programme by the Office of Forests on the Wahgi Swamps, now 1400ha, and particularly successful. These biomass resources are summarised in Table 13.

### a) Forest residues and sawmill wastes:

A detailed assessment of this category of biomass fuels is provided in Appendix 1. This has been updated from previous estimates (Newcombe and Weick, 1978) with the benefit of fieldwork in November 1978. The energy value of these wastes is obtained simply by assuming a figure of 40% moisture content on a wet basis, and a 67% energy conversion into usable energy forms such as oil, char, and gas by pyrolysis (see Tatom, 1979). The combined energy potential is  $193 \times 10^8$  MJ, or 80% of the energy value of imported petroleum products in 1975-76. This combined with the logging and sawmill wastes from the large number of sawmills, which are estimated at 34% of the volumes available from major forestry operations, provides  $259.7 \times 10^8$  MJ, or 107% of the energy value of 1975-76 imports. Notes on the economic availability of this energy are provided in the Industrial-Commercial papers (Newcombe, 1978), however, it is assumed that their exploitation in total will be economic by 2000. Apart from utilising these wood-wastes by various forms of destructive

Table 13      Selected Biomass Energy Resources

Biomass Source	Quantity Available	Energy Value (10 <sup>8</sup> MJ) (1)
Wastes at major sawmills (2)	339,000te	27.1
Residues and culls from major forestry operations (3)	2,072,000te	166.7
Combined sawmill and forest residues from small operations (4)	820,000te	65.9
Sago Palm (5)	300,000ha	60.4 - 323.2
Nipa Palm (6)	47,500ha (min)	35.4
Existing fuelwood cropping (7)	1,500ha (300ha p.a.)	4.0
Total		359.5 - 622.3

Footnotes

- (1) Ethanol is regarded as the energy form produced from Sago and Nipa Palm, and for the purpose of these calculations its energy value is taken as 85% of motor spirit, or 29.2 MJ/l, compared with its actual enthalpy value of 21.3 MJ/l.
- (2) See Appendix 2.
- (3) See Appendix 2.
- (4) 34% of the resource available from major existing sawmills and forestry operations. Estimated on a pro-rata basis using cubic metre input data to the sawmills (Office of Forests, 1978).
- (5) Area available for harvesting is estimated by Cavanaugh (1955) for the Sepik Provinces, and estimated from maps provided by J. Zeick (pers. comm, FPRC, PNG, 1979).
- (6) Only firm data available on the resource size is in respect of the Purari Basin from Liem and Haines (1978). This is a very small portion of the actual resource which has not otherwise been surveyed.
- (7) Firewood crops planted on the Wahgi swamp up to December 1978 (L. Martin, Provincial Forests Officer, Mt. Hagen, pers. comm., 1978).

distillation, or pyrolysis, it appears that their conversion to ethanol or methanol by acid hydrolysis and fermentation will be economic within the next decade (Newcombe et al, 1978, 1980). The energy value of these wastes represent 22% of the total imported petroleum products demand estimated for 2000, under our 'slow growth' scenario.

Of the total of 15 million operable hectares of forest available in Papua New Guinea, about 0.9 million hectares are currently being worked. New major forestry operations are being planned at Kapiluk and Umboi Islands and the total area under negotiation now, or expected to be in the near future, is 3 million hectares. If new planned forest plantings follow clear-felling operations, and selectively logged areas are well managed, which includes culling waste trees for energy, there is little doubt that the present level of energy from wastes can be maintained, and even greatly increased. Indeed the way is now open for pre-planned fully integrated energy and timber products harvesting of natural forest resources, and their continued management for higher and sustainable levels of productivity.

b) Sago Palms (Metroxylon spp.)

Sago palms are a naturally occurring source of almost pure starch, which can be extracted from the pithy core of the bole by simple hand-labour techniques. Starch can be converted into sugar by enzymatic hydrolysis for fermentation into alcohol. The energy self-sufficient means of converting sugarcane to ethanol using bagasse for factory heat and power appears to be an entirely applicable concept for Sago-alcohol. The cellulosic residues left over after extracting sago starch, and the woody sheath of the bole split off before processing can be dried and burnt to provide the energy requirements of the alcohol production process.

Sago palms are found in large natural stands on the Sepik River and in Gulf and Western Province freshwater swamp areas. Especially in the Sepik, floating factories on barges appears to be one way of developing an alcohol from sago industry. The smaller the industrial unit the more flexible, and suitable to economic development, the industry will be to the regions involved. Sago has been

investigated in Papua New Guinea as a source of starch for export at least 11 times between 1953 and 1972 (J. Zeick, Forest Products Research Centre, Papua New Guinea, pers. comm. 1979). Industries with the capacity to produce 30,000 tonnes or more of starch per annum have been envisaged, and in all cases no attempted industry has resulted. In the last instance a Japanese company, Toyo Menka, wished to construct a pilot plant of one ton/day capacity, but despite, in their view, a fair chance of success, relations between themselves and the Papua New Guinea administration did not lead to implementation. These investigations provide a data base, which, though still patchy, enables a cursory analysis of the potential for ethanol production for transport fuels for Papua New Guinea.

Estimates of the total sago resources remain crude, for although aerial reconnaissance can yield total plant distribution, the starch content of the plants in stands varies considerably, and access on the ground to the resource cannot be readily estimated from the air. Cavanagh (1955) estimates that there are one million acres of sago stands in the Sepik, and maps provided by Zeick (FPRC, pers. comm, 1979) indicate another 1.5-2 million acres in the Gulf Province region. Again, estimates of the productivity of these stands varies greatly. Cavanagh (1955) maintains that 6 to 7 boles yields one tonne of dried starch, and that annual yields of 7-8 boles/ha can be expected. Implicitly, about 1154Kg of starch can be obtained per ha. on average. This is conservative for the average sago log is 1400Kg of which 20% should be wet starch, or 280Kg. At 40% m.c. (wet basis assumed) we have 168Kg of dry starch (Toyo Menka, 1972; Edwards, 1961). Thus the annual renewable yield of a hectare of sago using Cavanagh's data is 1.15te/ha OD starch. Assuming 1Kg of starch will yield 0.6 l/ethanol, this transfers to an annual renewable yield of 690 l/ethanol per ha. At the other end of the scale detailed assessments of sago stands by Nakamura of Toyo Menka produced data showing 40-42 mature boles per ha, or in terms of the above data 3690 l ethanol/ha/year. In between these are data which compute to yields of 930-1340 l ethanol/ha/year (Morris, 1953) and 1340-1830 l ethanol/ha/year (Edwards, 1961, citing Office of Forests, Papua New Guinea, estimate).

All of the above sources agree, however, that past the first

rotation, when the natural stand becomes subject to semi-cultivation, the yield will increase considerably. In Table 13 the full range is recorded for readers to speculate on the implications for Papua New Guinea's energy future of each of the possibilities. A first glance at the economies of even the most small-scale of production units, 2 million litres per annum, look favourable. Assuming a range of purchase price per average bole (1400Kg wet weight) of from K3.40-K17.00 the production cost of ethanol ranges from 12.7-26.0 t/litre without accounting for possible bi-product credits of up to 2 t/litre. The real price of motor spirit in the Angoram Region of the West Sepik in the first quarter of 1980 was 39 t/litre. A programme to develop this Sago resource and to enhance it with new plantations has been reported by Holmes and Newcombe (1979). A full scale feasibility study on the production of ethanol from Sago in the Sepik is now under way. Social impact assessments will be complete by May, 1980; resource assessments by August, and engineering studies by October, 1980.

Table 13 shows energy yields in motor spirit equivalent energy terms (29.2MJ/l c.f. 21.3MJ/l for ethanol) as the emphasis is on import substitution for transport fuels. The Gulf Province resource is regarded as 1.5 times the size of the Sepik resource. The yield is 60.4-323.2 x 10<sup>8</sup> MJ or from 207-1107Ml of motor spirit equivalent. The lower figure is 22% of the 1985 estimated demand for transport fuels, 7% of the 2000 demand, and about 48% of present demand (slow growth scenario).

c) Nipa Palm (Nipa Fruticans)

Nipa palm is a tree of 3-4 metres high which grows in estuarine swamps. It is found right throughout South Asia and the Pacific. A sugary juice is tapped from the fruit-flower stalks equivalent to about 6% alcohol (by volume). A report on the Gulf Province area as part of the environmental impact studies for the Purari scheme (Liem and Haines, 1978) describes a stand of pure Nipa sp. of 48,500 ha, and estimated a potential alcohol yield of 2500 l ethanol/ha/year, based on data contained in Foxworthy and Mathews (1917) in respect of North Borneo. This represents 121.25Ml of ethanol, or 103.1Ml equivalent of motor spirit, compared with 125.9Ml imported during 1975-76. There is no comprehensive estimation available on the extent, and accessibility for this purpose, of Nipa palm stands in Papua New Guinea, so this must be taken as a minimum of the area of Nipa palm available.

J.F.K. Zeick, of the Forest Products Centre of Papua New Guinea undertook a literature review of this topic during the alcohol fuels pre-feasibility study of 1979. He calculated what he regarded to be a conservative estimate of yield as follows: 300 trees/acre, 1 pint of juice/tree/day, 200 tappings/year, gives 8000 gallons/acre/year, (i.e. approximately 480 gallons of alcohol/year (95%)). This is a yield of 5400 l/ha, which for the 48,500 ha referred to above in the Purari Basin, is 262Ml of ethanol or 223Ml of motor spirit equivalent. The lower estimate of yield given above is used in Table 13, even though this is being perhaps too cautious about the energy potential of Nipa palm in Papua New Guinea. A three year research programme aimed at establishing the costs and benefits of Nipa palm alcohol production, as well as Nipa sugar, vinegar and wood products has begun. Research staff and facilities will be in place at Baimuru in the Gulf Province by June, 1980.

d) Fuelwood cropping

For the moment the production of timber just for energy, on a commercial basis, is limited to firewood cropping of Eucalyptus robusta and E. grandis on the Wahgi Swamp in the Western Highlands Province. There have been 1400ha planted over the past 8 to 10 years, and a minimum of 300ha will be planted in 1979 under this existing programme. Yields after the first rotation, that is, after coppicing, are expected to be 20 ODT/ha/year on average, giving an annual yield, at 67% efficient energy conversion, of  $4 \times 10^8$  MJ/year. With expanded overall fuelwood demand and conversion from diesel to woodfuels in the local tea industry a further 2000ha of dedicated fuelwood crops is likely to be planted in the Western and other Highlands Provinces over the next two years, yielding at least a further  $4 \times 10^8$  MJ/year, excluding the existing commitment to plant 300ha more forest on the Wahgi Swamp in 1979.

A firewood cropping programme has been initiated by the Department of Minerals and Energy, in association with the Lae City Council, for the Atzera Hill system adjacent to Lae, as a result of this UNESCO research. This agro-forestry programme aims to have at least 200ha of fuelwood planted, mostly to Leucena spp., within four years from 1979. Again 20 ODT/ha/year is the anticipated yield in the mature phase of the rotation cropping programme (see Harris, 1978). There is little doubt that this agro-forestry approach to food and energy production will spread quickly if the Atzera Project proves successful.

In summary, Table 13 provides estimates of these biomass energy resources which range from 1.0-2.1 times the estimated 1985 demand, and from 31-64% of the estimated 2000 demand for imported petroleum products, using the 'slow growth' scenario. These data clearly do not include any estimation of the very considerable potential for dedicated energy farming of cassava, or tree crops, on a much larger scale than is now the case, and therefore must imply a very real potential for energy self-sufficiency at the turn of the century, should renewable energy source development be pursued vigorously during all of the next 20 years.

### 3. Harvesting solar radiation directly

Papua New Guinea has a surface area of land of about 46 million hectares which, at  $18\text{MJ}/\text{m}^2/\text{day}$  average insolation, represents a solar energy potential of  $3 \times 10^{15}\text{MJ}/\text{year}$ . Just 1% of this energy represents 740 times the 1975-76 total energy use for Papua New Guinea, excluding food or somatic energy used by the human population and hence the solar input to food production. Solar energy is used in many forms, but its use directly as radiation converted to heat or electricity is limited to crop drying and domestic hot water in the first instance, and to microwave repeater stations in the second. In Lae just 189, or 4% of 4858 dwellings had solar hot water heating in February 1978.

Needless to say, the potential is enormous for further exploitation of direct solar radiation as an energy source. The National Works Authority and the National Housing Commission are installing solar collectors in all high-covenant homes in Papua New Guinea owned by government, and incentives for the private housing sector to replace as many electric hot water systems as possible with solar systems are likely to exist with the revision of electricity tariff in early 1981.

In addition, recent discussions between the Electricity Commission and the Department of Minerals and Energy reveal that between 500kW and 1MW of outlying diesel stations are generating power at costs exceeding US\$0.70/kWh delivered, making even photovoltaic cells (PVC's) an economic form of electricity generation, at today's price of K10,000 per kWh peak, fully installed. With PVC's expected to fall to an installed cost of as little as K1000-2000/kWh peak by 1986, there is little doubt that direct solar electricity has enormous potential in Papua New Guinea's energy future.



### The Development Context

In this concluding section a few of the issues will be raised which must be faced when attempting to bring about energy self-sufficiency based on renewable energy sources. First, however, to summarise the previous discussions about, and descriptions of, the renewable resource base that is potentially exploitable, the magnitude of the energy available from these sources should be recounted.

Hydro-power, currently providing about 2% of the nations energy, represents at least three times the anticipated energy demand for all end-uses by the year 2000. The latter is forecast to be  $1160 \times 10^8$  MJ for the purpose of these comparisons. Just 1% of the solar radiation incident on Papua New Guinea is about 260 times this amount, and the sum of the energy potential of the biomass energy resources selected for discussion - existing forestry residues, sago and Nipa palm stands and existing fuelwood crops, amounts to between 31% and 64% of this estimated energy demand in the year 2000.

As extensive energy farming has been discussed as an additional option, the potential here can be placed in context by noting that 800,000ha would provide the equivalent of our reference 2000 energy demand, and this is 10% of the forest resource which is regarded as both accessible and suitable for large scale commercial forest development under present day economic conditions by the Office of Forests. The problems of acquiring this amount of land for continuous cropping are not difficult to imagine, but, nevertheless, the option for the longer term can hardly be dismissed out of hand.

So these data provide a back-of-the-envelope estimate of Papua New Guinea's renewable energy potential: it is, indeed, very large, but what criteria must be used to select the most appropriate pattern of energy resource development?

Some guidelines are provided by the national development goals espoused by Papua New Guinea. The eight-point-plan stresses balanced rural development, participation by small-holders in the economy, and equal distribution of goods and services and economic opportunities. The National Development Strategy also emphasises self-reliance and independence; in effect, political autonomy. Apart from the obvious emphasis then on renewable, locally available, energy sources for

self-sufficiency, it is clearly implied that dispersed energy sources should be favoured over concentrated ones. Put another way it is better that small communities are given the capacity to develop local energy sources in accordance with their needs, and under their control, than that they conform to the patterns of consumption imposed by a centrally regulated source distributed to them over great distances. An energy strategy designed in accordance with that criterion will promote small-scale production units, requiring lower levels of technical skill, over large-scale centralised production accompanied by extensive distribution systems.

It is not by any means the rule that larger units of production will yield significant economies of scale because the costs of distribution, and the reliability of supply, are often important factors counteracting this effect. In Papua New Guinea the example that can be drawn to illustrate this point is of large-scale hydro-power versus on-site generation, including micro-hydro resources.

The size of Papua New Guinea's hydro-power resource is misleading as a guide to the potential it has to service the existing pattern of energy demand. It is common for large hydro-power systems, say 50MW and above, to have costs of K1000-1500/installed kW, which is acceptable as a first cost for a resource with at least an 80% capacity factor. But transmission costs are very high and lines are often susceptible to collapse due to geological instability. From the Ramu system to Madang, the power line was out of service for up to 25% of the time in early years causing severe losses to industry and many costly side-effects of the higher demand on diesel back-up in the Madang township (such as cooling and refrigeration systems burning out with big voltage fluctuations when the towns chip-mill is forced to operate from the diesel back-up instead of hydro). The true cost of this mode of power supply have not been assessed, a fact which represents a deficiency in power systems planning. To date in Papua New Guinea the philosophy of large distribution networks dominates over localised autonomous systems, even though major industry frequently prefers the security of the latter. At the industrial level there are many instances where the local supply of electricity utilising steam generation from, or gasification of, wood wastes, or mini-hydro, is more economic, even without an honest accounting for the reliability and loss of grid-supply.

At the level of small rural communities the distribution costs of electricity through a grid system will almost invariably exceed those of the on-site alternatives now available, including micro-hydro, PVC's, wind-power, and wood/charcoal gasification systems for other than traditional village settings. As Amargwal (1978) has observed in respect of Indian rural electrification schemes, the costs of transmission over one kilometre equals the cost of production, and increases by the same amount for every kilometre thereafter.

The additional point to be made with respect to hydro-power is that the construction and maintenance of the supply and distribution system requires a high level of foreign technical skill. The high cost and low availability of these skills is now jeopardising the entire electric power system in Papua New Guinea.

In effect, the actual potential of hydro-power, a large and seemingly attractive resource, is much reduced by its real economic, strategic, and cultural deficiencies in the Papua New Guinean environment.

Another very important strategic consideration for energy planning is the question of 'how renewable is the energy source?'. Very simply, although biomass resources are 'renewable', and hydro-power is 'renewable', these must only be viewed as potentially, rather than invariably so. Harvesting biomass at an ecologically sustainable yield is a science learnt through careful observation and experimentation; it does not just happen. Hydro-power dams can silt up, reducing or removing the energy potential of the system, just because of poor management of the catchment, or through failure to recognise, and to observe, these parameters in site selection.

For these reasons it is strategically more sound to tap naturally renewable resources ahead of those which must be carefully monitored and kept in ecological balance to ensure their renewable nature, such as with cassava. In Papua New Guinea this means that Sago and Nipa palm in naturally occurring stands could represent sounder prospects for energy harvesting than cultivated energy crops. These swamp dwelling species are constantly nourished by nutrients flowing in from higher altitude water catchments, and there already

exists a high level of adaptation between them and their environment. Furthermore, harvesting these resources is not likely to be environmentally disruptive; the processes are simple and lend themselves to the use of casual labour, or small-holder businesses for collection, and the introduced state of semi-cultivation is likely to enhance overall productivity of the energy source.

Again the collection and conversion of forest residues will actually improve the timber resource of the natural forests, and ought to be able to be managed so that the residues and culls can be regarded as renewable on a 30 to 50 year rotation basis. Clear-felling and replanting of monocultures certainly increases the productivity of the area both of timber and energy; but it is fraught with dangers for the stability of the social and biological systems that were associated with the natural diversity of the previous forest ecosystem. The Madang wood-chipping operation has exposed these dangers, and the difficulty of coping with them in a developing country (Webb, 1977; Seddon, 1978).

Taking these factors into consideration the preferred path to energy self-sufficiency is one which utilises naturally occurring renewable energy resources, requiring little in the way of conscious management to ensure a sustained yield. The technologies of energy conversion should be as small in scale as possible, simple to construct and manage, hence creating little ongoing dependency on imported expertise. This optimum pattern will not be favoured in all circumstances, but the criteria which determine its suitability should always be foremost when determining the direction of energy development in any region.

Appendix 1

Forest Residues and Sawmill Wastes available for energy  
conversion in Papua New Guinea, 1979

Province	Sawmill or Log Despatch Depot	In Field - including culls ( '000te)	
West New Britain			
Bialla	17	180	
Stettin Bay	35	288	
East New Britain			
Open Bay (1)	30	276	
Rabaul	10	50	
Morobe			
South Pacific Timbers (2)	53	159	
SPT leases (3)		130	
Bulolo-Wau (4)	75	117	
Madang			
Jany-Gogol (5)	15	500	
Wewau-Gogol (6)	4	54	
New Ireland			
Central	39	90	
Nakmai	6	90	
Southern Highlands			
Kaupena	12	27	
Ialibu (7)	5	9	
Central			
Kupiano	29	72	
Port Moresby Mills (8)	10	30	
Sub-Total (10)	339	2072	2411
All Small Sawmills (9)	820		820
TOTAL			3231

Energy Conversion Data:

Moisture content of wood (wet basis) = 40%

Energy content of an oven dry tonne of wood = 20,000 MJ

Conversion Efficiency by Pyrolysis, including drying = 67%

Thus  $3231 \times 10^3 (1-0.4) \times 20,000 \times 0.67 = 259.77 \times 10^8$  MJ

Footnotes:

- (1) Data derived from fieldwork by K. Newcombe, J. Tatom and E. Hammermaster, November, 1978. Conversion factor for log input volume (V) to available waste in the field is taken as 1.88V. Recovery of timber from log input

volume to sawmill is taken as 0.4V. This data is likely to be an underestimate of actual potential. For example, no allowance is made for recovery of waste timber felled for road networks.

- (2) From detailed waste flow analysis at SPT by M. Page, CSIRO, Melbourne, November, 1978, and from (1).
- (3) From analysis of timber leases already harvested and still available for secondary logging within a 30km haul of Lae, M. Page, CSIRO, Melbourne, 1978.
- (4) Data provided to J. Tatom and M. Page by CNGT and Boudrez Timbers, November, 1978, as part of consultancy to Department of Minerals and Energy, Port moresby, Papua New Guinea.
- (5) Personal communication, S. Leslie, Jant Co., March, 1979, R. Bruce, Provincial Forest Office, Madang, November, 1978, and assuming double logged volume left as wastes in field after clear-felling.
- (6) Personal Communication, Wewak Timbers Co., Madang, November, 1978, and (1).
- (7) Personal communication, G. Spillane, Lama Sawmill, Ialibu, November, 1978.
- (8) Personal communications, B. Hermisec, Forest Products Research Centre, Boroko, Papua New Guinea, February, 1979.
- (9) Data derived from Office of Forest Reports on minor sawmills log volume inputs and assumptions made in (1).
- (10) Wherever the data source is unspecified, detailed local assessment of the resource has not been made, and average data from other similar sawmilling or log export operations has been applied.

Chapter 3

Energy in Industry\*

\*This chapter is a substantially rewritten and updated version of "The Industrial/Commercial Papers" by Newcombe, K., 1978. Technical Paper PNGE/T6, Papua New Guinea Human Ecology Programme, Centre for Resource and Environmental Studies, Australian National University, Canberra. 52pp.

## Introduction

The data and the ensuing discussion on the patterns of end use of energy in the industrial-commercial sector of the energy economy of Lae is part of a series of energy policy papers leading to an integrated evaluation of the energy future of Lae and its hinterland. The object of this research, as with research into energy use in the other sectors of economic activity, is to determine the potential for energy conservation, and for the development of alternative, locally available renewable energy sources in a manner compatible with the national development strategy of Papua New Guinea (CPO, 1976).

The City of Lae was chosen for this research because it is the second biggest city in Papua New Guinea, and the foremost industrial city. As opposed to Port Moresby, Lae is connected with an extensive hinterland by the country's only major highway system. Thus, the pattern of its industrial development and the prospects for adapting alternative energy sources, and for reducing, without disruption, the overall flow of imported fossil fuel energy through this urban ecosystem, are likely to be similar for other major towns, especially coastal ports linked to the same hinterland by a highway system. In that sense, it is anticipated that options identified for the energy future of Lae, will, to a large extent, be indicative of the options available to Papua New Guinea as a whole.

## The present context of industrial and commercial energy use

The distinction between commercial and industrial activities adopted here is similar to that adopted elsewhere and forms a convention for sectoral end use analysis (SRI, 1972; Newcombe, 1975; Kalma, 1976). Commercial activities are here defined as "wholesale and retail trade, communications, finance, property, public authority, defence, amusements, hotels and restaurants". The difference in this analysis is that we have separated out the government activities from the commercial sector and we present them as a distinct sector, or activity, in their own right.



Lae is a small industrial centre by global standards. It has a population of 45,000 people and a growth rate estimated to be 5% per annum, at least 2% per annum of which is attributed to migration from the hinterland (Bureau of Statistics, 1978). There are no more than fifty substantial manufacturing or processing factory operations in Lae. The import dependency of Papua New Guinea is reflected in the number of importers and wholesalers operating out of Lae - eighteen in 1977/78. Many of the industrial and commercial activities are sales and service operations, such as the fifteen (15) motor and heavy equipment dealers, and the ten (10) or more road building contractors based in Lae.

The commercial sector is dominated by food retailers, including six (6) large supermarket chains, and twelve (12) busy and prosperous fast food outlets.

All the large or medium-sized factories, wholesale and retail outlets, financial institutions, professional services, churches and clubs are owned or operated almost exclusively by Australians, Germans and other Europeans. There is only one major company of corporate status which is nationally owned and operated: the Namasu Company, which operates wholesale and retail outlets and shipping and wharf facilities throughout the country. In addition, there is a rapidly growing trucking company (Roadways Inc.) and a very small ice block manufacturing company that are owned and operated by nationals with expatriate management support. At the time of writing, only two Papua New Guineans were on boards of directors of companies operating in Lae. Many large Australian companies operate wholly owned subsidiaries under local names. Generally, the technology transfer from Australia to these subsidiaries has been made without modification to better suit local conditions; in particular, without changes in the energy source, or the processes of energy management. While Australia and Papua New Guinea show some parallels with regard to the future availability of liquid petroleum fuels, the social and political incentives to conserve fuel, and to develop a low-energy industrial base are much greater for Papua New Guinea than for Australia. Australia does have globally significant coal and natural gas reserves, and is expected to produce a proportion of its petroleum requirements well into the 1980's.

The starting point for evaluating future scenarios for energy development and end use in any country must be a thorough and detailed understanding of the nature of the present patterns of energy use, and of the country's cultural and economic history. The Australian administrators and Australian industry have largely set the format for energy use in Papua New Guinean industry in particular, and for Papua New Guinea's towns and cities in general. The data which follow are therefore a representation of the end product of such interacting cultural and economic forces.

The working hypothesis of this research is that there are economically viable alternative energy strategies, including the exploitation of new energy sources and new kinds of energy management, that are much more appropriate to Papua New Guinea's development as an independent nation state than are those that are presently in use.

#### The data base

The size of Lae is such that every major activity can be observed within a relatively short period firsthand by one observer and the managers of particular commercial and industrial activities can be sought out for personal discussion. Because of this convenient setting, an attempt was made to contact and hold open ended discussions with the managers of every major industrial and commercial activity.

Using lists of employers in Lae supplied by the Department of Labour and Industry (Colin Huddy, pers. comm. 1977) and updating these through observation in the field, contact was eventually made with 140 industrial and commercial concerns during an eight week period.

A standard set of data requirements was provided by mail in advance of a personal visit (by the author in all cases). These data were either obtained at the first interview or arranged to be collected on another occasion. Wherever possible the physical plant in use in the factory was inspected. Data were collected on the

- following:
- (1) energy use during the period July 1976 to June 1977;
  - (2) energy use during the last accounting period, e.g. one week, one month or one quarter;
  - (3) seasonal variation in energy use;
  - (4) purpose for which energy is used;
  - (5) temperature of heating or cooling processes in production;
  - (6) energy conservation practices or intentions;
  - (7) waste generation and disposal;
  - (8) plans for future development including changes in energy use.

Only one industry, which happens to be only a minor user of energy, refused to co-operate with the survey. Most owners or managers of commercial or industrial enterprises were both co-operative and very interested in the nature of the research, and in many cases alternative patterns of energy management were investigated as a result of the discussions.

With respect to data on petroleum products, all oil companies, gas suppliers and minor agents which distribute these products to industrial and commercial consumers supplied extensive data on imports and exports for the Lae urban ecosystem, within a detailed categorisation of end uses we provided for them. This allowed for extensive cross checking and verification.

Statistics on electricity consumption that were provided by companies could be so easily cross-referenced to actual accounts rendered by the utility. The Papua New Guinea Electricity Commission does not operate a data recall system on sectoral end use patterns, but data were made available upon request in respect of major individual accounts and every assistance was given within the constraints of a very limited data retrieval capacity.

The prices paid for fuels varied depending on the size of the end use consumer and the energy company they dealt with. There was considerable competition by all the companies for distillate, motor spirit and kerosene markets, and by smaller companies for liquefied petroleum gas markets. However, variations in prices were marginal, and competition tended to be created by variation in arrangements for servicing clients with the products, or, in the case of agents, assistance with merchandising.

Average prices for the range of energy forms in use by industrial and commercial enterprises in Lae are provided in Table 14.

### Thermodynamic quality

One important feature in the data analysis that is attempted here which distinguishes this data set from many previous attempts at building detailed sectoral end use matrices (SRI, 1972; Newcombe, 1975A; Kalma, 1976) is that consideration is given to the thermodynamic quality of the energy forms in use. Most analyses of the flow of energy use in regional or national industrialised ecosystems have attributed equal value to a megajoule of electricity, petroleum, charcoal or solar energy. However, the most important criterion is that of "available work"; a measure of the thermodynamic quality rather than the thermodynamic quantity of the energy form. The further the temperature from the ambient temperature the greater the amount of potentially available work, which is to say that very low and very high temperature heat is much more valuable than low temperature or "low grade" heat (AIP, 1975). Tables of energy use provide much more assistance to energy planning if the fuel type in use can be matched with the temperature at which it is used, and compared with the minimum temperature required to perform the task in question. The practical importance of identifying low grade heat requirements, as distinct from high grade heat requirements, is that many high grade heat sources of high thermodynamic quality are essentially wasted on end uses which can be satisfied by low grade heat. For example, water can be heated more efficiently (in thermodynamic terms), and usually more economically by the low grade heat of unconcentrated solar radiation than by electricity.

Information on thermodynamic quality also facilitates a better understanding of the minimum energy required to perform specific tasks and so gives the physical upper limits to energy consumption which can be usefully compared with the prevailing economically or culturally based limits.

Nevertheless, despite this recognition of the need to consider thermodynamic matching in energy planning, the calculations of 'minimum energy requirements' in second law thermodynamic terms

TABLE 14 : ENERGY PRICES IN PAPUA NEW GUINEA 1977-1978

<u>Energy form</u>	<u>Basis for costing</u>	<u>Toea per Megajoule</u>
Motor spirit	- retail	0.60
	- wholesale	0.51
Diesel	- retail	0.42
	- wholesale	0.35
Kerosene	- retail (Lae Trade Store)	0.52
	- retail (Village Trade Store)	0.63
	- wholesale	0.36
Liquefied petroleum gas	- wholesale (bulk)	0.88
	- retail (5.0Kg cylinders)	1.58
	- retail (4.5Kg cylinders)	1.98
	- retail (2.3Kg cylinders)	3.08
Electricity	- average domestic consumer, Lae	1.84
	- common low covenant household, Lae	4.63
	- common high covenant household, Lae	1.60
	- average industrial/commercial consumer, Lae	1.72
	- average maximum demand industrial consumer, Lae	1.15
Firewood	- when sold in Lae and Highlands as about 2.5Kg bundles very dry medium hardwood	0.23
	- Lae City Council Firewood Supply Scheme	0.07
Fuel oil	- No.6 boiler or furnace oil	0.25
Pyrolytic oil and char	- Production costs K32-K42/tn. Selling Price K54/tn.	0.18
Cardboard and paper	- Preparation, shredding and transport K3.50/tn. 15% m.c. (dry basis) 17MJ/Kg	0.02
Sawdust and offcuts	- Burnt in Dutch oven type grate boilers K5/tn factory gate, 50% m.c., 12.5MJ/Kg	0.04

COMPARISON BASED ON COMBUSTION EFFICIENCIES FOR HEAT OR STEAM RAISING

	Combustion Efficiency	Effective Price
Fuel oil	0.80	0.31
Diesel oil	0.85	0.41
Pyrolytic oil and char	0.80	0.23
Cardboard and coffee husks	0.60	0.03
Wood residues	0.60	0.07
Electricity - maximum demand tariff	0.95	1.21

(see AIP, 1975) have not been systematically performed for all end-uses in Lae. To this extent the evaluations that are made in this series of documents on energy futures for Lae are not exhaustive.

### Industrial energy use

Data on the end use of industrially used energy forms for each kind of industrial activity in the Lae urban ecosystem is presented in Table 15. A simple summary of the data is presented in Figure 6, a pie chart of energy use by individual activity for the reference year of 1976 to 1977.

Glass manufacturing, which occurs in only one factory, is the largest industrial end use of energy - followed by food manufacturing and the timber industry. Together these industrial activities use 73% of the energy used in the industrial sector. The timber industry is dominated by one major sawmill which, quite apart from its internal energy use, is a key industry in energy terms. We shall elaborate upon the reasons for this later.

The food manufacturing industry is split into two major categories; baking and brewing. Baking of bread and biscuits uses 33%, and brewing of beer uses 45% of energy used in the food manufacturing industry. A further 6% is used by the soft drink industry. There is considerable use of low grade heat at temperatures of less than 100°C in the brewing industry. Direct solar radiation for pasteurising beer and for bottle washing will become attractive options if the present plant is expanded. However, alternative fuels which are compatible with the existing fuel combustion equipment in breweries in Papua New Guinea are likely to be in economic use ahead of direct solar radiation for most in-plant end uses.

The building and construction industry, including earth moving, road building, iron and steel fabrication, and building and joinery uses 17% of industrial energy use. About 70% of this energy is used in road construction and maintenance. This industry will remain prominent for the foreseeable future as roads are pushed out towards Finschafen in the east, and the Highlands Highway and the roads to Wau and Bulolo are slowly upgraded and sealed.

TABLE 15

ENERGY USE IN THE INDUSTRIAL SECTOR, LAE, JULY 1976 - 1977 (MJ x 10<sup>5</sup>)

INDUSTRIAL ACTIVITY	ELECTRI- CITY	DISTILLATE		PETROL		Lique- fied Petrol- um Gas	Fuel Oil	Fire- wood	Kero- sene	Other as Speci- fied	TOTAL AS LOW GRADE HEAT					
		Non- Transport End-Use	Transport End-Use	Non- Transport End-Use	Transport End-Use						<100°C Total Non- Transport End-Use	% of Total Non- Transport End-Use	<150°C Total Non- Transport End-Use	% of Total Non- Transport End-Use	Total Energy Use	% of Industrial Energy Use
Bricks and Concrete	5.32	12.45	14.53	8.44	10.50	1.22					12.45	45	12.45	45	52.46	0.8
Glass manufacture and recycle	144.78	178.86	2.89	9.95	14.06	120.88	1834.27								2305.69	35.0
Chemicals (incl. Paints, Soap)	25.00	92.82	5.36	-	17.44						51.31	44	51.31	44	140.62	2.1
Timber	103.77	553.44	248.64	-	93.33			249.88			395.17	50	395.17	50	1249.06	19.0
Food Manufacturing and Processing (not incl. Primary Industry)	266.00	446.29	14.97	-	71.75	13.79	394.74	10.42	13.21	Coffee Husks 28.89	431.38	38	491.93	44	1260.06	19.1
Iron and Steel Fabrication	69.58	40.34	15.39	13.0	24.10	5.72			1.12						169.25	2.6
Building and Joinery	16.08	8.10	81.59	-	59.58										165.35	2.5
Plastics	7.60				2.02	1.31					1.31	15	1.31	15	10.93	0.2
Paper, Cardboard and Printing	11.39	39.38	4.38		23.73	3.42							42.80	76	82.30	1.3
Motor Vehicles and Equipment (incl. Sales components)	72.71		25.14		122.55										220.40	3.3
Earth-Moving, Road Building	10.57		716.08		44.65										771.30	11.7
Electrical Engin- eering, Appliances	14.69				65.48	1.71									81.88	1.2
Plumbing	3.28		13.70		4.56										21.54	0.3
Rubber (Tyre Processing)	17.28	24.91			9.93								24.91	59	52.12	0.8
TOTAL	768.05	1396.59	1142.67	31.39	563.68	148.05	2229.01	260.30	14.33	28.89	891.62 (18%)	1019.88 (21%)	6582.96	100.1		
% use of energy form inc. Transport	11.7	21.2	17.4	0.5	8.6	2.2	33.9	4.0	0.2	0.4	(=100.1)	(Non-transport end-use = 4876.61)				
% use of energy form excluding Transport	15.8	28.6		0.6		3.0	45.8	5.3	0.3	0.6	(=100.0)					

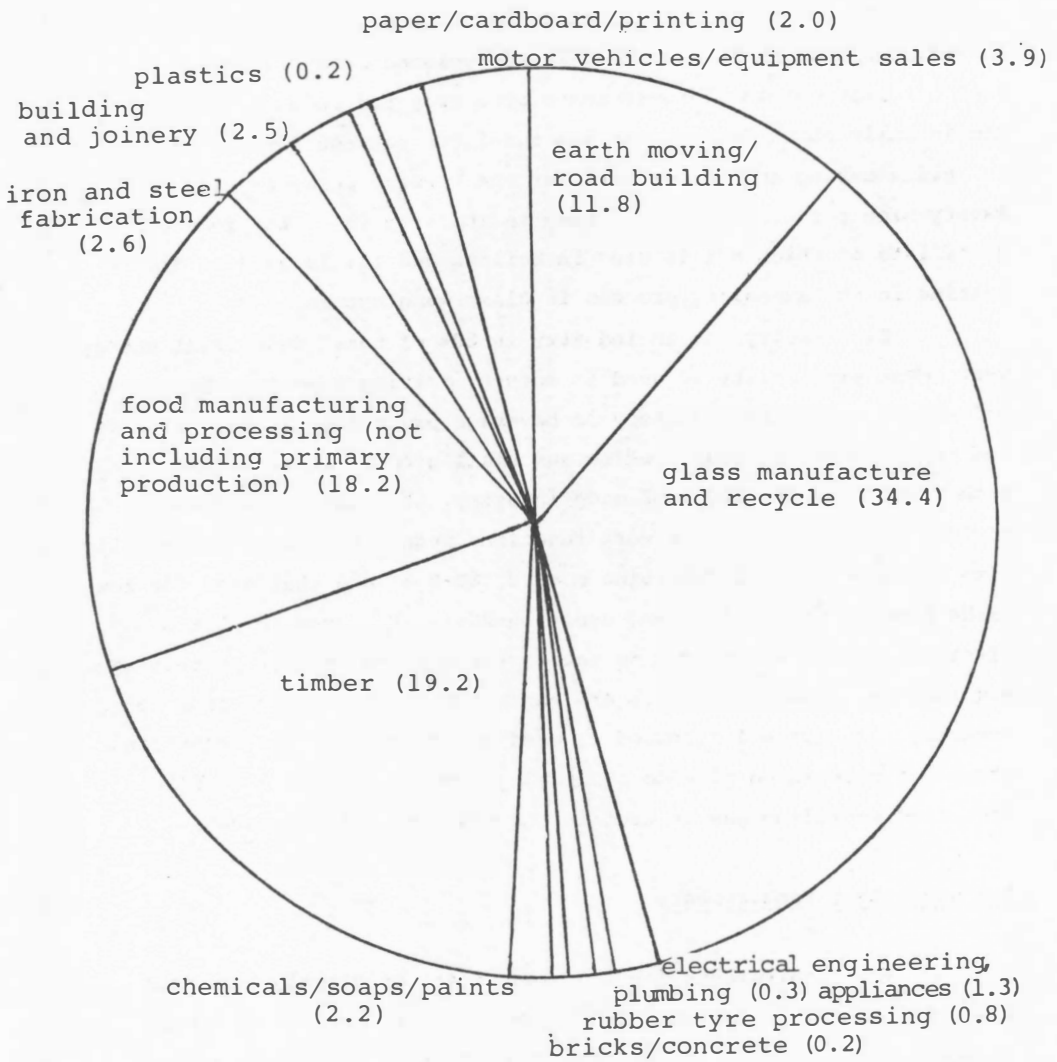


Figure 6 Industrial Sector: Energy Use (%) by Activity



The energy forms currently used in industry are indicated in Table 15, and can be more readily appreciated from Figure 7. Fuel oil provides the largest share of energy for industry and its use is split about four-fifths and one-fifth between furnace oil for glass making and boiler fuel for the brewery respectively. Twenty-nine per cent of energy used in industry is in the form of distillate of which 80% is used in boilers and 13% is used as direct heating in the annealing process in glass manufacture.

Electricity use in industry is 60% of total industrial energy use. Most electricity is used in motors, driving saws in sawmills and joineries, conveying machinery in beverage production lines, bakeries and for processing flour, coffee and small goods. It is estimated, from first hand knowledge of each industry, that electricity is divided into that used for work functions requiring thermo-dynamically high quality energy for driving motors (80-85%) and that used for low grade heating and cooling end uses (15-20%). For example, 51% of electricity used in brewing in Lae is for cooling in beer processing and storage. All other fuels are currently of minor importance to industry. Almost all firewood is used by the sawmill for generating steam for processing plywood and curing timber and over 80% of the liquefied petroleum gas is used in the glass annealing process.

#### Low grade heat requirements

The requirements for low grade heat, of firstly less than 100°C and secondly less than 150°C, are, as a proportion of total industrial energy use, 18% and 21% respectively. Low grade heat is provided by low pressure steam generation or through combustion of fuels for direct heat transfer. In all instances of low grade heat requirements for hot water or direct heat, it is technically feasible to completely satisfy demands with direct solar radiation, although this may not be the most economic alternative fuel for these purposes. The use of electricity for heating and cooling purposes which require only low grade heat sources adds a further 3% to 18% of total energy use to the energy bill. It is obvious that these data are indicative of the maximum possible replacement of high grade by low grade heat

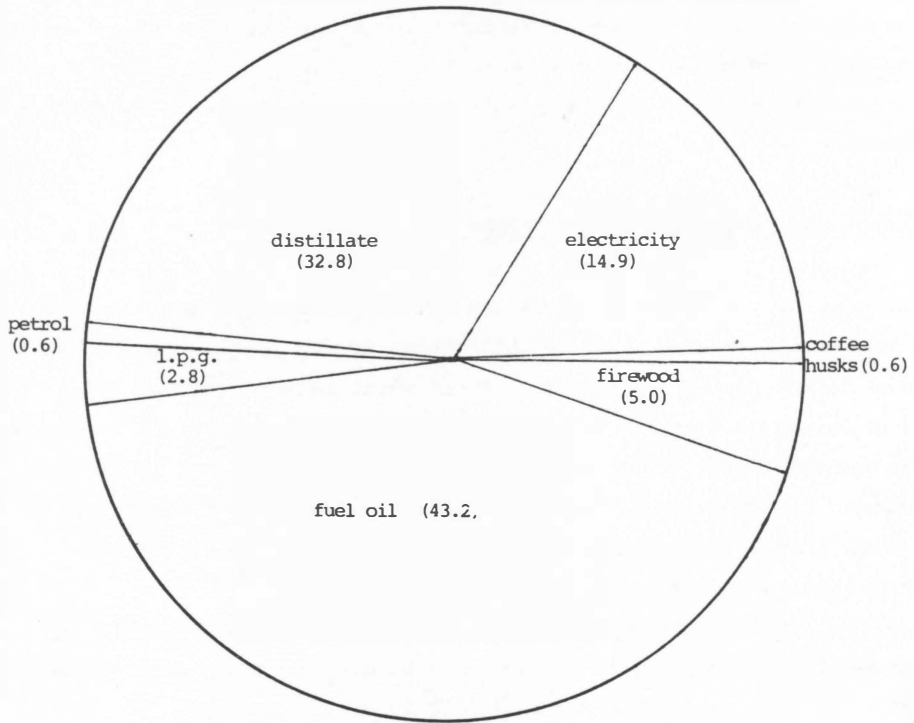


Figure 7 Industrial Sector: Energy Use (%) by Fuel Type  
(Transport component omitted)

sources, and not of actual potential for making this substitution. For example, one of the most thermodynamically appropriate sources of low grade heat is solar radiation, but for both technical and climatic reasons no more than 75% of the industrial low grade heat requirements could be met by direct solar radiation even if it were the most economic of the available energy sources. The question of alternative sources of energy will be discussed in detail in a later section.

### Energy use in the commercial sector

Of the total extrasomatic energy use in the Lae urban ecosystem, 26% is used in the industrial sector whereas just 2% is used by the commercial sector. It is worth reiterating though, that in the calculation of these proportions, transport energy use is counted in the transport sector, thus the energy used in the regular distribution of goods and services to and from factories, or within factories and commercial enterprises, does not enter the industrial and commercial accounting.

Table 16 presents a detailed analysis of energy use in the commercial sector, and the proportion of energy use in each commercial activity is clearly demonstrated in Figure 8.

There is no dominant activity in terms of energy use. However, several of the most energy intensive activities are of critical importance to the stability of the urban ecosystem. These include the activities of food marketing and distribution, the energy suppliers, wholesale traders, supermarkets and retail stores. Each of these use between 9% and 13% of the total energy use within the commercial sector. Supermarkets in Lae are very substantially food outlets, with only minor stocks of consumer durables. Hotels, motels and guest houses also use about 10% of energy use in the commercial sector. Reclassifying these commercial activities into those dealing substantially with food supply and retailing, the distribution and retailing of other goods and services, religion, recreation, professional services and education, then the pattern of energy use is simplified to:

food related services 35%

other goods and services (shops, cleaning) 43%

Table 16

ENERGY USE IN THE COMMERCIAL SECTOR, LAE, JULY 1976 - JUNE 1977 (MJ x 10<sup>5</sup>)

Commercial Activity	Electricity	Distillate		Petrol		Liquefied Petroleum Gas	Kerosene	Other Solar	Total as low grade heat		Total Energy Use	% of Commercial Energy Use
		Non-Transport	Trans- port	Trans- port	Non- Trans- port				<100°C	<150°C		
Hotels, Motels and Guesthouses	61.55	8.30	-	0.81		16.23		0.34	28.06	28.06	87.23	10.4
Restaurants	6.89			0.98		12.80			3.45	3.45	20.67	2.6
Milk Bars, Food Bars	12.12			10.78		14.10			3.03	3.03	37.00	4.6
Food Marketing and distribution	24.30		26.13	44.65	10.01					10.01	105.09	12.8
Supermarkets	45.23		11.86	10.68		0.82				33.92	68.59	8.4
Large Retail Stores	33.74		20.17	21.85							75.76	9.2
Small Retail Stores	9.07										9.07	1.1
Trade Stores	12.30										12.30	1.5
Businesses (e.g. Lawyers, Insurance)	5.10										5.10	0.6
Wholesale Traders	17.09		19.04	59.31							55.44	11.6
Energy Supply (Petroleum Products, Electricity)	42.02		26.79	35.62							104.43	12.7
Banks	11.80		8.65	16.52							36.97	4.5
Churches, Missions	3.0		4.98	2.64							10.62	1.3
Clubs	8.3		3.46	3.06		0.63					15.45	1.9
Recreation, Amusements (e.g. Theatres, Sporting Facilities)	7.9										7.90	1.0
Travel (Sales components)	9.65										9.65	1.2
Education												
- University	54.80			26.31							81.11	9.9
- Lae Tech. College	7.91										7.91	1.0
- Private Schools	4.00										4.00	0.5
- Government Schools	5.30										5.30	0.6
Laundry, Dry-cleaning	0.61	20.76		1.56					20.76	20.76	22.93	2.8
<b>TOTAL</b>	<b>382.68</b>	<b>29.06</b>	<b>121.08</b>	<b>234.77</b>	<b>10.01</b>	<b>44.58</b>		<b>0.34</b>	<b>50.30</b>	<b>94.23</b>	<b>822.52</b>	<b>100.20</b>
%	40.6	3.5	14.7	28.6	1.2	5.3					99.90	
% minus transport (466.76)	82.0	6.2			2.1	9.6		0.1			100.00	

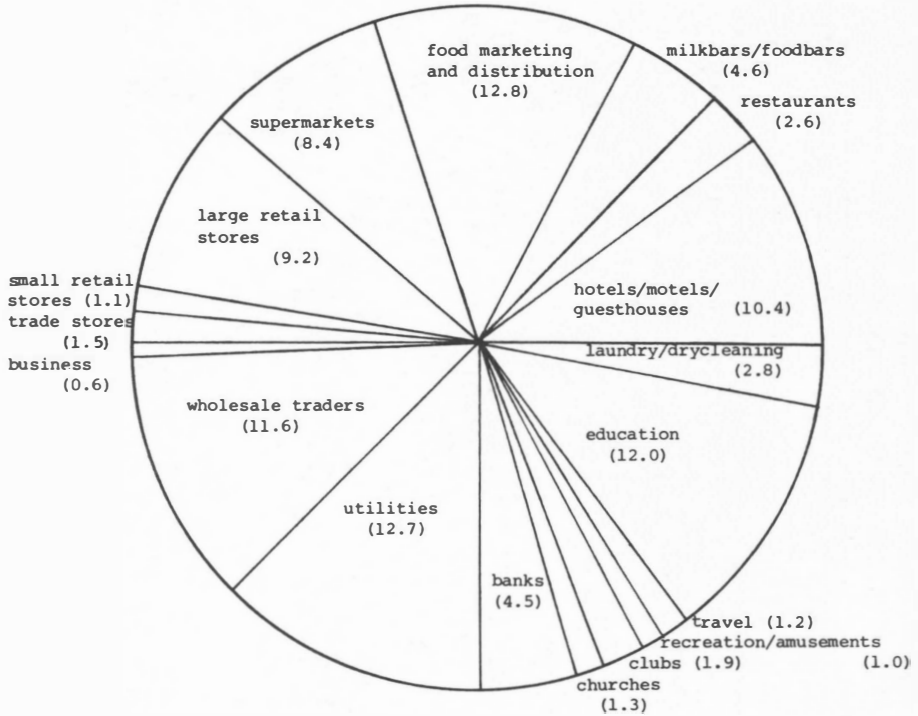


Figure 8 Commercial Sector: Energy Use (%) by Activity.

recreation (clubs, theatres) 3%  
 religion 1%  
 education (universities, colleges, schools) 12%  
 professional services (doctors, lawyers, accountants,  
 finance) 6%

In the food related services energy is used for refrigeration, cool storage, cooking, lighting and water heating. Excluding air conditioning, at least 20% of the energy demand in food-related activity is for low grade heat at temperatures less than 150°C, as indeed it is for the commercial sector as a whole.

The data gathered on patterns of energy use in each commercial activity include the numbers and kinds of air conditioners and their times of operation. This allows a rough estimate to be made of the energy used for air conditioning, other than for refrigeration. This estimate is  $120 \times 10^5$  MJ, or 25% of total commercial energy use. This estimate, plus the low grade heat demand estimates for refrigeration and water heating, indicate that there are substantial opportunities for utilising direct solar radiation for cooling and water heating in the commercial sector, given appropriate economic incentives.

It is obvious from Table I6 and from Figure 9, that electricity is the major form in which energy is used in the commercial sector and its common end uses have been described above. Hotels and laundries use distillate to fire boilers for low pressure steam for cleaning linen, and LPG is used by fast food outlets for cooking, and in the case of one hotel, for heating water. LPG and distillate combined comprises 16% of the energy use in the commercial sector.

### Renewable energy sources in the Lae economy

As one of the objectives of this research is to identify renewable and locally available energy sources which are not now exploited, but which present likely options for development in the foreseeable future, it is first worth clarifying the role which renewable energy sources now play in the industrial and commercial sector of Lae.

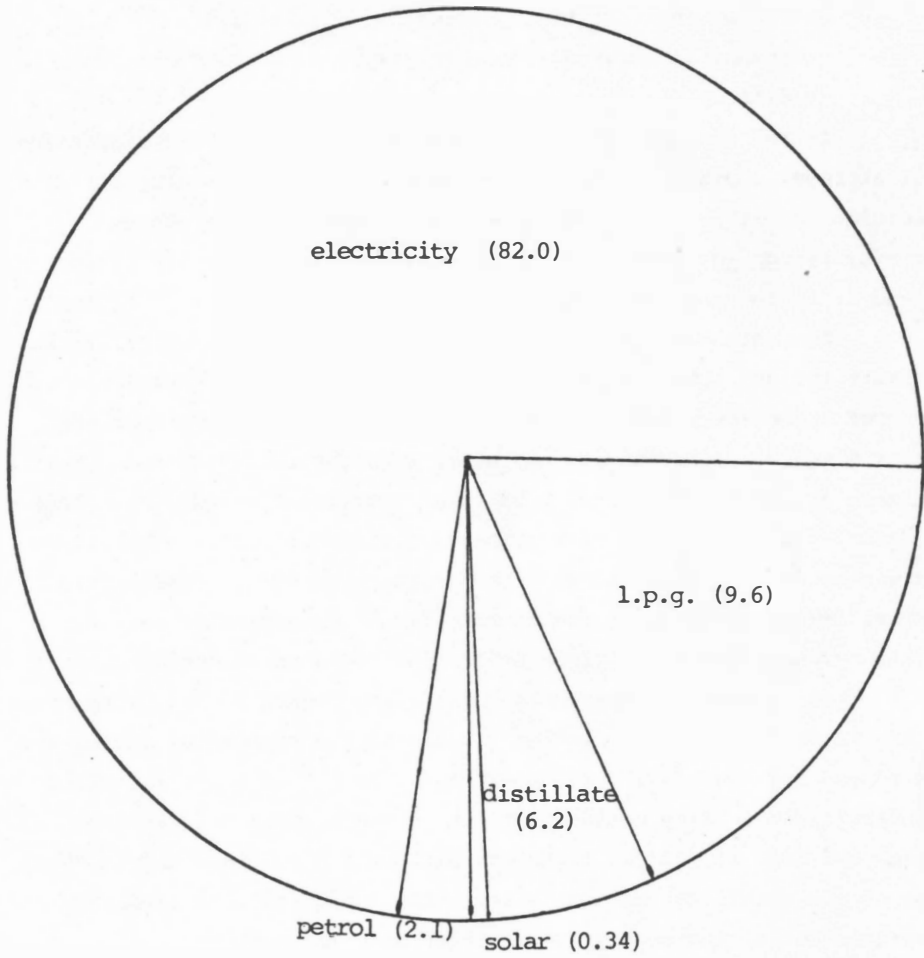


Figure 9 Commercial Sector: Energy Use (%) by Fuel Type  
(transport component omitted)

In recent years electricity generation for the city of Lae has been switched from diesel generators to hydroelectricity from the Ramu River hydro-power development. Now, all but emergency back up power is hydro-electricity and, as such, it is a renewable energy source. Apart from muscle power, the only other important sources of renewable energy presently in use are firewood and coffee husks (see below).

Renewable energy sources, nevertheless, require careful management to ensure the renewable characteristics of their source. For example, poor regard for water catchment areas behind the hydro-power head water system can lead to siltation and rapid depletion of the power generating potential. Similarly, firewood cropping of forest resources must be carefully planned and managed in order to sustain high yields over many decades.

There is only one instance of direct solar radiation being used by a commercial or industrial enterprise in Lae and only two instances where waste materials, (coffee husks in fact) are used as fuel, although the firewood in use at South Pacific Timbers is otherwise regarded as a waste material.

For industry, these renewable resources contribute 22% of total energy use; this figure being comprised of 73% from electricity, 25% from firewood and 2% from coffee husks. In the commercial sector renewable energy sources contribute about 82% to total energy use, with all but 0.1% of this - the solar radiation portion - being hydro-electricity.

It is obvious that the mere existence of renewable energy forms is not the only determinant of whether or not they will be exploited. There are many renewable sources whose characteristics are such that the energy costs of trapping them are greater than the energy they supply - or that the technological and social circumstances are such that their exploitation is prohibitively costly in economic or social terms. Even though Papua New Guinea holds vast hydro-power potential - the third largest in the world - the cost of hydro-power already exploited there is many times the cost per unit of energy delivered from hydro-power sites in New South Wales and Tasmania in Australia, and it may well eventuate, that in some circumstances, other renewable sources of electricity, and even other forms of energy, will



be more economic and more appropriate for national development than is hydro-electricity. In the following section some of the options identified by this research for the development of alternative energy sources for Lae, and potentially for other regions of Papua New Guinea, are presented.

#### Alternative sources of energy for industry and commerce

During the course of fieldwork and of the data analysis, the options for the development of renewable, locally available energy sources have become clear and have been placed in the perspective of current and anticipated energy use patterns in the industrial and commercial sectors. Alternative energy sources will be discussed in terms of near term - viable now or within three years, medium term - becoming viable between 1980 and 1990, and long term - becoming viable in the 1990's. Of course, the allocation of potential energy sources to each of these categories is partly by subjective judgement and will be defended in each instance. To refer to energy sources as "viable" in this context is to infer that they will be economically competitive or socially desirable even if economically marginal and that development and distribution can occur with substantially Papua New Guinean equity and expertise.

#### Energy from wastes

Wastes are an important source of alternative energy forms. They lead into a discussion of energy conversion technologies which have wider application than just the transformation of wastes into high quality energy sources. During the in-depth survey of industry, data were compiled on the wastes generated by industrial processes. These data will be presented in full in another report in this series, however those wastes which can be converted to energy, or can themselves be combusted as an energy source will be discussed here. Table 17 lists these wastes in relation to their origin and status for future availability. The discussion of the use of these wastes proceeds from the minor to the major sources.

TABLE 17 : AVAILABLE WASTES WITH ENERGY POTENTIAL GENERATED  
BY INDUSTRY IN LAE URBAN AREA, 1976/77

Waste	Origin and amounts (tonnes)	
Sawdust, shavings and wood offcuts less than 1" diameter	17,900	Sawmill
	1,200	Joineries
Wood offcuts larger than 1" diameter	33,400	Sawmill
	1,800	Joineries
		Industrial sites
Paper trimmings	70	2 Printers
Cardboard	1,000	Package makers
		Bottle recycler
Coffee husks	175	2 Coffee mills
Tyres	430	2 Tyre companies
		Service stations
Waste oil	720	Service stations

### Coffee husks

Up until three years ago, coffee mills in Lae used distillate burners to provide low grade heat to roast green coffee beans. At that time the cost of distillate to dry the 2,500 tonnes of coffee reaching the Lae market was of the order of K6,300 and increasing rapidly. Enterprising managers investigated and ultimately installed simple, small furnaces to burn coffee husks. Of the green coffee beans which have between 18% and 25% moisture content, it can be anticipated that about 12.5% by weight will be thin and dry husks. The husks were blown into the furnace at a constant rate, with the heat so generated being directed to the roasting chambers in the same manner as with the heat from the distillate. With the capital cost of these furnaces at less than K10,000, and with the relegation of the distillate used in the initial firing of coffee husks, the costs are able to be recovered within a two year period and a difficult problem of waste disposal is partially solved. Currently, about half of the 350 tonnes of coffee husks are burnt to provide heat for coffee processing and the remainder are available for other end uses in Lae for the cost of their transport. The economic saving to the coffee mills is approximately K11,000 (K1 = A\$1.25; US\$1.42) and the fuel saving is about 76,000 litres of distillate ( $19 \times 10^5 \text{ MJ}$ ) per annum. This small local development in waste recycling has provided local experience in the use of such waste materials for direct heating or steam raising and in the local construction and maintenance of simple conversion equipment. This technology is similar to that which can utilise shredded paper and cardboard as a source of low grade heat either directly, or as a boiler fuel.

### Cardboard and paper

Packaging and printing factories in Lae generate 320 tonnes of dry offcuts and trimmings each year, all of which are dumped or burnt on site as a means of disposal. Two hundred and fifty tonnes of this waste is dry cardboard from the manufacture of cardboard containers. The energy value of this cardboard is rated at 17.5MJ per Kg. Thus its total energy potential is about

44 x 10<sup>5</sup> MJ, which just exceeds the energy value of the distillate used to raise steam to cure and process the cardboard in the factories. The cardboard manufacturing company has serious difficulties in disposing of the accumulating waste, which now fills the available space on site to overflowing. Disposal costs in terms of labour, transport and dumping fees are undoubtedly of the order of several thousand kina. If the firing chamber of the boilers were altered to burn the shredded cardboard, with a small amount of distillate to fire the material, and blowers and shredders were installed, then the cardboard could replace 95% of the distillate now used, saving 42 x 10<sup>5</sup> MJ. The costs are anticipated to be similar to those experienced in the conversion of heaters used in the coffee industry to take coffee husk feedstock. Similarly, a local package printing company dries its product with low grade heat provided by the combustion of liquefied petroleum gas, a high quality energy source. The demand for LPG for this end use by the company has trebled within 18 months, and now is 7 tonnes per annum. The paper trimmings generated by the operation amount to 40 tonnes per annum, with almost double the energy value of the LPG. Again, the use of simple shredding, controlled feeding and modified combustion commitment equipment could mean a cost effective recovery of the energy in the paper wastes. After early discussions with the management of the company concerned, an internal assessment was made and now the company will be installing equipment to utilise paper wastes when their new, enlarged premises are constructed in the near future. The anticipated energy savings are 3.5 x 10<sup>5</sup> MJ, which, although small, will create another model for industry to follow in the utilisation of similar waste products generated elsewhere.

A further 750 tonnes per annum of dry cardboard waste, in the form of used beer cartons, are baled, transported to the city's landfill site, and buried. The disposal costs are about K7,500, and the energy value of this material is 132 x 10<sup>5</sup> MJ or 314 tonnes of fuel oil equivalent. As much as 85% of this energy is recoverable by pyrolysis, or it can be burnt directly as a source of low grade heat with about 75% of the efficiency of diesel or fuel oil. This latter option might appear the most attractive because the effective price of cardboard and paper waste energy is at least 10 times less than fuel oil and diesel oil. However the initial capital cost of the combustion equipment to

burn these wastes (e.g. Dutch ovens, pelletisers/ovens/fluidised beds) is often prohibitive because it involves a total replacement of oil-fired systems and a much larger area for combustion, fuel storage, handling and preparation. Hidden costs related to the latter and an unattractive return in the 3-5 year periods which industry usually views its investments.

### Waste Oil

Sump oil from mechanical workshops and service stations is currently discarded. This oil is commonly filtered and re-refined as a boiler fuel in parts of Australia and New Zealand. Provided simple well-made equipment can be found, a local recycling industry could provide a minimum of  $80 \times 10^5$  MJ equivalent of boiler fuels for industry by 1979 and at least  $200 \times 10^5$  MJ by the early 1980's. Consideration is being given to the recycling of lubricating oil in New South Wales in Australia where it is estimated that 50 megalitres of this oil are recoverable each year. The most important barrier to the direct incineration of this oil is the emission of lead derived from the lead contained in petrol. In 1978 the New South Wales Government believed that lead pollution would fall to acceptable levels when the proposed reduction to 0.4 grams of lead/litre took place, and that the collection and re-refining of lubricating oils for blending with fuel oil will become economic when Australia adopted world parity pricing for indigenous crude oil (P. Landa, Minister for Planning and Environment, New South Wales, pers. comm. 1978). It is now (1980) clear that the re-use of lubricating oils as an energy form in Papua New Guinea is an immediate option, for research on the availability of the product and industries' interest in its use for the Department of Minerals and Energy has revealed that several companies in Lae are installing systems for their combustion.

### Tyres

Experiments conducted by the Bureau of Mines, United States Department of Interior (Wolfson et al, 1969) have shown that the energy recoverable from the destructive distillation of tyres is technically feasible, although I am unaware of the availability of an economically competitive process for the extraction of oil and gas from truck and car tyres. The yield of energy products from destructive distillation is temperature dependant, but with an initial temperature of  $500^{\circ}\text{C}$ , one tonne of truck tyres may be expected to yield about 50Kg of oil and

140 cubic metres of gas. Including all tyres that are available for conversion in Lae, the energy yield would be roughly  $9 \times 10^5$  MJ for oil and  $25 \times 10^5$  MJ for gas. The pyrolysis of tyres may be marginal at the present time but direct combustion is probably economic. Boilers are available now from Japan which are designed to take a whole tyre in their combustion chamber and to burn it completely without pollution.

#### Sawmill Wastes and Forest Residues

These materials represent the most important alternative energy source both locally and nationally. Their conversion to useful energy can take several forms, including direct combustion as firewood, controlled combustion of sawdust to yield offgas, carbonisation to charcoal, or pyrolytic conversion to oil char and gas.

##### (a) Direct combustion

Decades ago, modified Dutch ovens were designed and used in Africa for the wet sawdust and agricultural residues such as coffee husks (EAIRB, 1945). These designs are suitable for direct heating requirements or steam raising in rural areas in Papua New Guinea where there is an abundant supply of suitable lignocellulosic<sup>1</sup> materials close to the point of industrial demand. Similarly, it has long been a common practice on the West Coast of the United States to heat sawdust in a primary combustion chamber under controlled conditions and to burn the offgas in a secondary chamber, directing the heat to industrial end-uses (Panshan, et al, 1962). However, the economic viability of sawdust combustion is greatly influenced by transport costs, for moving moist, as received, sawdust feedstock any distance is usually not economic. Even in urban Lae, the energy losses from burning wet sawdust, and the cost of the water-wall boilers that would likely be utilised makes direct use of sawdust economically dubious in comparison with pyrolysis of this fuel to more convenient energy forms, especially if the sawdust or shavings are not produced on-site. The alternatives of drying the sawdust for use in more compact combustion systems such as fluidised beds, or pelletising it require both additional and expensive technology, and a source of cheap heat. Such systems are often energetically and economically self-defeating.

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<sup>1</sup>Any plant materials which are combustible.

During the 1970's many efficient, easily managed, low maintenance boiler systems or heat exchange systems, have been developed and are being marketed. They warrant close attention from any industry with substantial energy requirements, including electricity, and their own lignocellulosic waste materials (see, for example, AFIJ, 1974, 1975, 1976, 1976A and B). The potential is great for total integrated energy systems with on-site generation of electricity and steam or low grade heat recovery, where previously distillate or fuel oil was burnt to raise steam directly, electricity was imported to the site, and wood or other combustible wastes were discarded or burnt purely for disposal. A timber products company in Lae (Pacific Timber Products) evaluated such an integrated system as economically feasible during 1977 and will install combined electricity generating and steam kiln drying equipment during 1978-1980. This equipment will utilise most of the 1100 tonnes of wood waste produced annually and generate all but a few percent of the  $104 \times 10^5$  MJ of electricity now imported. The conventional approach to the generation of electricity using woodwastes is direct combustion firing steam-boilers coupled with turbo-generators. While entirely feasible, the process is an extremely capital intensive route, and, as we will show later, usually cannot compete with the flexibility of an integrated heat and electricity generating system with pyrolytic conversion as the basic technology.

Again the trade-off that has to be made is between the much greater capital costs of equipment for combustion of wood residues, and the more difficult and expensive transportation and handling and storage problems, against the much cheaper energy from this source. As Table 1 indicates, wood residues were effectively 4.5 and 6 times cheaper than fuel oil and diesel oil respectively in 1977. As industry now uses combustion equipment which is unable to burn wood residues, but which is capable of modification to burn pyrolytic fuels (see later), this is strategically the best immediate option. In the longer term, however, the direct combustion of wood residues must be a serious competitor with any fuel derived from them, and only sensitive analysis of the economic circumstances of each proposal will determine the best option.



Plate 1. Voco Sawmill, Lae. Here some 50,000 tons of wood waste are burnt annually.



(b) Carbonisation

Wood can be upgraded as fuel by carbonising it to produce charcoal. The advantage of charcoal is that it is a smokeless fuel easily pulverised to form a fuel oil-char mixture, or gasified, for use in conventional oil-fired boilers. It is 30% by weight, and 50% by volume, of dry wood per unit energy, making transportation much more economic than wood.

Charcoal is in many ways an ideal fuel for industry in Papua New Guinea. It is currently in use in the tea industry in the Western Highlands, though in fairly unique circumstances, in that it is used as a supplement to firewood in order to keep up temperatures in a poorly designed combustion/heat exchange system. Its potential lies with the diversity of viable forms of end-use it presents. It can be burnt directly in standard solid fuel combustion chambers or in fluidised bed systems. It can be fired as a pulverized fuel in conventional powered fuel firing systems which have either been installed as such, or retrofitted to suit. Finally it can be used as the feedstock in gasification systems which again are either attached as retrofits to the front of conventional package oil fired boilers or installed in combustion systems designed from the start for gasification. Only the gasification technology is new, at least as applied to modification of package oil boilers, though gasification units are available off-the-shelf from Cleaver Brooks, U.S.A. for retrofitting their own oil fired boilers for use with solid fuels such as charcoal or pelletized wood waste.

A great deal of research and evaluation is now being applied to charcoal production technology suitable for Papua New Guinean conditions (Harris, 1979). This work, funded by the Department of Minerals and Energy, and conducted in association with the Forest Products Research Centre, is focusing on scaled up versions of the so-called West-Indian retort which has only been reported to date as a small-holder technology (Chandler, no date). This system offers the advantages of short carbonisation cycles, usually less than 8 hours, efficiencies of 20-30% (charcoal as % by weight of oven dry weight of charge plus firewood), high fixed carbon in the charcoal, and very simple management. No data were previously available on yields, and management overheads for labour and fuel-stock preparation, and the longevity of these retorts is yet to be

established for each variation we now have under trial. In addition to this work on retorts a missionary organisation, AID, is about to test a Ugandan Mark IV steel kiln in the highlands of Papua New Guinea and the Department of Minerals and Energy is examining the potential of the Missouri kiln in the U.S.A., and the Brazilian beehive kiln for large-scale production systems (see Newcombe et al, 1980).

It is now clear that charcoal is a significant near term fuel both for local industrial use, in rural and urban areas, and for export as an expedience to establish large scale production to be directed later to local consumption. Within urban Lae, however, as with other urban centres with major sawmill wastes, charcoal production cannot compete with low temperature pyrolysis. Pyrolysis can yield 85% of the energy of the input feed as useful products compared with 40-50% when charcoal is the sole product.

#### Pyrolytic Conversion of Sawmill, Forestry and Crop Residues

Pyrolysis is the thermal degradation of a lignocellulosic material into simpler carbon compounds of oils, charcoal and gas. The oils are referred to by people with long experience in wood distillation as pyroligneous acids, or soups (Levy, 1977, Harris, 1978). In the jargon of the workers associated with the new versions of low temperature pyrolysis dealt with here the same compounds are referred to as pyrolytic oils, as they do behave in many ways similar to No.6 Fuel oil, and the nomenclature is meaningful in terms of their intended end-uses as a substitute for fuel oil and lighter diesel oils.

The charcoal fraction is referred to as char, basically because it is produced in the form of fine charcoal. It could equally well be referred to as 'charcoal breeze', the term for 'fines' or finely divided charcoal in the charcoal trade.

The gases are low BTU gases (about 150 BTU/cu.ft), and usually must be used at the site of production due to the poor economics of storage.

Pyrolysis is not a new process but is fundamentally the nature of changes which take place when materials are heated in an air-starved environment. The variations possible are very many in the way the process is managed and the nature of the feedstocks and the form and selective proportion of the end products. Recent reviews of the process

under commercial development are provided by Tatom (1978), Cousins (1976) and Klein (1980).

The form of pyrolysis proposed for application in Papua New Guinea (Newcombe, 1978), and now under development at the pilot research stage, and the first phase of commercial application, is the low-temperature pyrolytic conversion method sophisticated by Georgia Tech, and the U.S. licensee of the process Techair, and the developer, American Can.

The original work on this batch-continuous, packed bed process is described in Georgia Tech reports for the EPA, the early sponsor of the R. and D. work (Tatom et al, 1976, 1977). Commercial application of this technology by the American Can Corporation was in Cordele, Georgia, in a 50 ODT/day unit which only generated for three years (Knight et al, 1978, 1979).

Versions of this technology, appropriately geared in terms of scale and management requirements for developing countries, have been built at the one-off pilot scale in Ghana (Chiang et al, 1977, Powell, 1979), Indonesia (Tatom et al, 1977) and of course, Papua New Guinea (Tatom, 1979). Feasibility studies are still underway in Senegal, (Tatom, 1977a) and a unit of similar design is believed to be operating in the Philippines.

The Department of Minerals and Energy now has the largest unit to be considered since the Cordele plant under design for construction in late 1981. The 3 ODT/day pilot plant at the University of Technology, Lae is the research unit for the DME for both design and operational improvements, and product evaluation and end-use trials. A further three ODT/day unit is proposed by the author for integration in a copra production system where the gas from pyrolytic conversion of coconut shells displaces distillate for drying, and the oils and charcoal will be byproducts.

The pyrolytic converter now under design for Lae will be placed at the South Pacific Timber Co. It is expected to process up to 7,300 ODT of sawdust and shavings per year, and provide the equivalent in net output of 27% of the 1977 heat requirements of Lae's industry. For each tonne of dry waste 250 Kg's of char, and 100 Kg's of oil are expected to be produced. The gas will be used to drive electricity generating sets, either diesel, spark ignition, or gas turbine. The exhaust from this system will be used to dry incoming feedstock to 10% m.c. w.w.b.,

or less. The gas output is expected to be about 30-35% of the energy in the dry feed, or about  $1270 \text{ M}^3/\text{ODT}$  of feed at  $5.5 \text{ MJ/M}^3$ .

### Pyrolytic Oils

Pyrolytic oils are expected to have an energy value of 24-25 MJ/Kg, and the char 29-30 MJ/Kg. The oils are highly oxygenated, being about 30% Oxygen by weight. They have less than 0.01% Sulphur which is an advantage in their use as a fuel. Compared with fuel oil they are more dense, 1.08Kg/l c.f. 0.82 Kg/l (Pober and Bauer, 1977), hence on a volume basis they have about 75% of the energy per barrel of fuel oil, and only about 60% on a weight basis. Pyrolytic oils from wood waste are less viscous than fuel oil and more viscous than heavy diesel oil. At room temperature ( $25^\circ\text{C}$ ) No.6 is 2262 cP, No. 2 fuel oil 20 cP, and pyrolytic oil about 230 cP (Knight et al, 1977).

The viscosity of pyrolytic oils falls greatly with increased temperature, as does fuel oil, and they reach comparable viscosity (50-60 cP) at  $60-80^\circ\text{C}$ , enabling their use in similar combustion systems.

The acidity of pyrolytic oils ranges from pH 2.2 to 3.0, and is due to carboxylic acids. Acidity increases with temperature and corrosion of 304 stainless steel occurs at  $50-60^\circ\text{C}$  at 0.05-0.10 ml/yr for municipal solid waste pyrolytic oils (Pober and Bauer, 1977). Pine-bark and sawdust derived oils have a pH of 2.9 at ambient (Knight et al, 1977) and are not expected to cause severe problems during short-term storage in mild steel drums. Combustion systems for pyrolytic oils alone will have to use high grade stainless steel to avoid corrosion problems. However blends of pyrolytic oils and fuel oils are much less corrosive and mixtures of this oil with distillate offer advantages for the combustion of these fuels.

Flame stability is as great with pyrolytic oil as with No.6 fuel oil, and the blends, which are in fact dispersions, fire as well. Firing can be either as a blend, or with two feeder lines and mixing at the nozzle (Schweiger, 1979). Finney and Sotter (1978) concluded from test firing pyrolytic oils from Douglas fir bark in an 80 HP firetube boiler with conventional oil burners that the oil can be successfully burned over a wide range of conditions and is suitable for a large power station boiler with properly designed storage and handling systems.

Tests on the combustion of pyrolytic oils in small boilers in mixes with distillate will proceed during the first half of 1980 in Lae. While small boilers are the favoured end-use for these oils, they can equally be mixed with fuel oil for use in the local glass furnace. The higher luminosity of the flame is said to be desirable for glass production.

### Char

Char will be the major output of the pyrolytic conversion system. Since it is already in a finely divided form, the options for its combustion are not as many as for lump charcoal, although this is not expected to be a significant factor in char sales.

There are three major options now being considered for the end-use of char produced in Lae, micropulverized fuel firing, char-oil mixtures, and char gasification.

#### i) Micropulverized-powdered fuel firing

Micropulverized fuel firing, or powdered fuel combustion is an established form of coal combustion, and for other fine volatile materials such as sander dust. Burning pulverized char requires a change in the existing combustion equipment away from the presently installed oil fired, firetube boilers. Fuel can either be delivered in lump form to the face of the boiler, and passed through an attrition-hammermill grinder and then to the burner, or it can be delivered in powdered form to the boiler and direct fired without treatment at the boiler face.

It has been difficult to locate pulverized fuel systems in the comparatively small size range of boilers and other combustion equipment in general use in Papua New Guinea. The bottom end of the range of off-the-shelf equipment is for 300 HP boilers, or thereabouts, and this is the top end of the size range of most industrial boilers in Papua New Guinea. Exceptions in Papua New Guinea include boilers installed in the oil palm industry, which utilise palm nut waste, and the No.6 fired utility boilers for the Bougainville Copper Mine. While there are as yet no detailed costings of new pulverized fuel systems in the 300 HP size range for Papua New Guinean industry, it is clear that the cost of totally replacing the existing combustion equipment is greater than straightforward modification to burn the same fuel with the same, or even half of the oil displacement achieved by the PF option. As usual though there are circumstances in which powdered fuel firing is

economically attractive.

The Bougainville Copper Co. (BCL) dries its copper concentrate with distillate in fairly unsophisticated combustion conditions. Here micropulverized char is both technically and economically viable, and detailed drawings of the retrofit, and detailed economic analyses are now in preparation in order to compare this option with others available. These driers use 2000 l/day of distillate, and depending on ore moisture content, 2.8l/te of ore is required to dry to specification.

The char for this drying operation would come initially from the South Pacific Timber complex in Lae, and later from Bougainville, as the char produced in Lae was directed to the Lae market, and a pyrolytic converter located on Bougainville. The char would be transported in micropulverized form in 1 tonne nylon fibre bags (Taicon reusable bags). The bulk density of the char is raised to 0.75Kg/l or higher with micropulverization making transportation over long distances much more viable.

ii) Char-oil Mixtures (CHOM)

Char-oil mixtures are a direct parallel of coal oil mixtures (COM), for which a great deal of R and D is in progress in the U.S. (Rodriguez and Sell, 1978; Bergman et al, 1978; Demeter et al, 1977).

Charcoal, or pyrolytic char, can be micropulverized to have 95% pass through 200 mesh (73 microns) and blended with No.6, or diesel fuels, up to 40% by weight, and perhaps higher, for use in conventional oil fired systems. This option is available even for quite small boilers, although it is being thought of for large utility boilers in particular in the U.S.A. Demeter et al (1977) ran tests on a 20% coal-oil slurry (w.w.) in a 100 HP Cleaver Brooks firetube boiler at the Pittsburgh Energy Research Centre, and found a greater than 99% carbon combustion efficiency. The strategic advantage of CHOM in Lae is that a substantial proportion of oil could be displaced without major changes in existing combustion equipment. This was recognised early in the development of the Papua New Guinean pyrolytic fuels programme (Newcombe, 1978) and tests were run in late 1978, and May 1979 on powdered char-oil mixtures, first on a small diesel-fired boiler and then on a 250 HP Cleaver Brooks boiler in the South Pacific

Breweries in Lae. These tests at 10% and 20% w.w. char in oil proved convincingly that the mixture could be burnt as efficiently as fuel oil in unmodified oil-fired boilers. Details of the tests are contained in Liversidge et al (1980). The same problems faced long term firing as those reported for COM firing. Nozzles abraded quickly, fuel lines and pumps showed marked signs of wear, and an ash layer of 3 ml lined the boiler tubes after several hours of firing. Combustion efficiencies were, however, excellent. Exactly the same experience was obtained by Demeter et al (1977) when they fired a 30% CHOM mixture using char from the same design of pyrolytic converter installed now in Lae. They achieved excellent flame stability and combustion efficiency, but even after 1000 hours of CHOM firing the ash layer was only 3 ml, indicating that this was the stable level of the ash deposit.

As a result of the experience of these tests, tungsten carbide nozzles, and feeder lines, abrasion resistant fuel pumps, and effective ash removal systems have been identified. These are now available commercially from Cleaver Brooks, U.S.A. as a package for retrofitting their standard oil-fired firetube boilers to burn CHOM.

Following through the commercial potential of CHOM the Department of Minerals and Energy have solicited co-operation from oil companies on the preparation, storage and transportation of CHOM in Papua New Guinea. The Mobil Oil Company have concluded, from their tests on the stability of CHOM for No.6 and distillate, that while the char particles will ultimately settle out of suspension, suitably cheap additives are available as byproducts from oil refining which would facilitate rapid recovery of a homogenous mix with slight turbulence.

These findings complement those of Ekmann and Bienstock (1978) working on the stability of coal-oil mixtures. Mobil have concluded, in recent communication with the Department of Minerals and Energy, that the best method for handling CHOM is to prepare concentrates of char and oil at the pyrolytic converter site, and to distribute these to industry. At the industry the oil company would undertake to blend the concentrate and fuel oil or diesel to the desired end-use proportions for the consumer concerned.

This approach is compatible with experience on two counts. Firstly, the best way to pulverize char appears to be a wet ball-milling

process with diesel fuel or No.6 in the mill with the granules of pyrolytic char. This avoids problems of explosive dust, dirty working conditions generally and losses of char. Secondly, we know that concentrations of fifty percent oil (No.6) and char, and greater are stable without stabilizers added, making the storage and handling of the concentrate relatively simple.

One great advantage of CHOM over COM or straight fuel oil is that charcoal has negligible Sulphur, hence the SO<sub>2</sub> emissions are much lower. Accordingly in Lae, the problem of acid attack on galvanized iron roofing and exposed metal structures in and around the industry are reduced.

The char-oil mixture option is an important and now proven option. It will remain a major option for the displacement of fuel oil in the local glass furnace, although this end-use has yet to be tested. However, an even more attractive option for retrofitting existing boilers to use pyrolytic char and charcoal is gasification.

### iii) Gasification

Gasification of solid wastes, especially of forestry and crop residues is an established option receiving more attention in recent times (see Goss, 1978). The fundamentals of the process are the same as for producer gas production for which German, French and British technology is well established through experience prior to, and during, the two world wars. In this geographic region during the same period a host of research and development proceeded which is still extant, such as the work by Pederick (1976, 1977) in Australia, and the developments in New Zealand during World War Two (Bailey, 1978), and more recent interest by Cousins (1978).

It is only in the past three years though that gasification technology has been applied to retrofit oil fired boilers and combustion equipment. Cleaver Brooks, U.S.A. have developed a package now available commercially for the gasification of charcoal, or pelletised lignocellulosic wastes, which is small and conveniently plugs into the face of their oil-fired boilers (Chronowski et al). Developmental work is proceeding along similar lines in the Forest Conversion Technology section of the CSIRO, Division of Building Research, Victoria, Australia (Liversidge, Page and colleagues).



The advantage of gasification is that only clean air and burnt gases enter the firing chamber of the boiler. Ash is removed at the point of gasification, and particulate matter in the gas is filtered out as the gas passes back through the hot bed in the mode of a down-draft gasifier.

Preliminary estimations of the cost of conversion of the South Pacific Brewery boilers in Lae appear very attractive with payback periods for a total fuel handling and gasification system well within the twelve months at today's prices for char and No.6 fuel oil. Detached investigations and analysis of this and other options for the use of solid fuels will be available in August 1980 from the Department of Minerals and Energy arising from a U.S. AID funded feasibility study by the U.S. DOE, Cleaver Brooks, U.S.A., and the Mitre Corporation.

#### Development of pyrolysis in Lae

The commissioning, in February 1980, of a 3 ODT/day micro-version of the larger plants proposed for Lae has been mentioned. This demonstration and R and D facility will enable controlled tests on all feedstocks likely to be available in Papua New Guinea to determine their oil, char and gas yields. The facility will also greatly expand our knowledge of the relationships between bed conditions and product yield. Finally it will be used as a training facility for national engineers.

The major pyrolytic converter for the South Pacific Timber Company is now under design, to be completed in August 1980.

The first stage of the SPT pyrolysis development will be the 25 ODT plant and the second stage will be the totally integrated scheme utilizing all wastes. The energy yield from the first stage will be 3375 tonnes of char and oil (300 day basis),  $1013 \times 10^5$  MJ or 2411 tonnes of fuel oil equivalent. This is 27% of all petroleum products in use in Lae in 1977. This does not include the use of the off-gas, which represents a further  $337 \times 10^5$  MJ.

In terms of long-term regional self-sufficiency, the supply of wood waste materials is more than adequate. There are a further 40-45,000 ODT per annum of wastes available at Wau and Bulolo which are within 140 kms of Lae. In addition, recent investigations have shown that within an average haul of 30 kms radius from Lae

there are 1,825,000 ODT<sup>1</sup> of wastes and tree culls whose removal would be beneficial to commercial timber production (M. Page, CSIRO, Pers. comm., November, 1978). This represents 65 years of supply at current levels of industrial energy use. At a 5% per annum growth rate in industrial energy use these waste resources combined with the SPT timber leases can be managed to represent a renewable energy source roughly 1.2 times the demand by the year 2000 (assuming all wood is converted to char and oil and surplus off-gas is flared and there is no programme for conservation of energy).

#### Economics of pyrolysis at Lae

Analyses by consultants to, and members of, the Department of Minerals and Energy predict the cost of stage 1 pyrolysis products to be a minimum of K32 per tonne (1978 Kina) of oil and char, compared with the March 1980 price of fuel oil at Lae, of equivalent energy value, of K127 per tonne (Tatom, 1979). Conversion of all wastes, including the logging of wood hearts and peeler log cores from the veneer mill will cost K42 per tonne of oil and char. The cost of scavenging and converting the enormous volume of field wastes, based on conservative estimates (M. Page, Forest Conversion Technology Section, Division of Building Research, CSIRO, Victoria) brings product costs to K90 per tonne in 1978 kina, which compares with a cost of K168 per tonne for diesel in equivalent energy terms in 1980. This latter comparison is valid because apart from two industrial consumers in Lae, the product will compete with diesel, not fuel oil. The initial capital cost of the pyrolytic converter is about K47 (1978 Kina) per installed kW thermal, at an 80% capacity factor. More detailed up-to-date costs of production will be available by September 1980 from design work for construction of the 25 ODT/day plant now in progress.

#### Solar

To this point only indirect sources of solar energy have been discussed. These have been forestry or agricultural resources produced via photosynthesis from the sun's radiant energy. There are, however,

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<sup>1</sup>Recently revised to 2,310,000 ODT (Page, pers. comm., December, 1978). The 1.825M ODT figure is used for calculations in the text.

several means of direct conversion of solar insolation into useful energy for industrial and commercial purposes that have potential in the Lae setting.

(a) Solar water heating - up to 50°C

Domestic solar water heaters have been installed in Papua New Guinean towns for at least fifteen years. Recently, a local production industry has developed simple solar collectors which are well suited to Lae's solar radiation regime. For domestic purposes these flat plate collectors, with crude black paint over copper sheeting and piping, repay purchase and installation costs within 3 years.

In industry and commerce in Lae there is to date only one application of direct solar radiation; flat plate collectors to heat water in a small guest house. Water heating in industry and commerce to temperatures up to 50°C is not substantial. In the industrial sector it is estimated that water heating to this level uses  $40 \times 10^5$  MJ, and in the commercial sector about  $50 \times 10^5$  MJ. The latter is made up substantially from water heating in hotels, motels and guesthouses. Here, electricity or LPG is used for heating the water for bathroom use when simple solar collectors are already an economic and convenient substitute. From the viewpoint of self-reliance, substitution of LPG by solar radiation for water heating has the highest priority, whereas the substitution of hydroelectricity by solar, which is exchanging one renewable resource for another, is primarily an economic and thermodynamic consideration. In summary, solar heating of water in industry and commerce to temperatures of 50°C is a near term option already economically and technically feasible, carrying the social benefits of supporting local industry and creating employment opportunities for semi-skilled labour at a much greater rate than with any other option. Perhaps  $15 \times 10^5$  MJ of LPG could be saved in this way, and  $75 \times 10^5$  MJ of hydro-power can be replaced by a significantly cheaper and more suitable energy form.

(b) Solar airconditioning and refrigeration

The data collected indicate that about  $110 \times 10^5$  MJ of electricity are used for cooling in industry, including airconditioning. Commercial office airconditioning is estimated conservatively to use  $120 \times 10^5$  MJ, and refrigeration in the commercial sector, in supermarkets, food and marketing distribution, clubs and hotels and motels is estimated to use about  $53 \times 10^5$  MJ. These figures are the maximum substitution possible of solar radiation for electricity for this end-use. Solar energy airconditioning in particular is likely to be economic in the near future in Papua New Guinea, and its suitability for isolated areas with no access to electricity would make it a technology well worth thorough investigation. Energy conservation strategies to reduce total energy demand for these end-uses are also important considerations.

During the past three years the Japanese have developed solar airconditioning plants which operate at an input temperature of  $75^\circ\text{C}$  - a temperature easily obtained from efficient flat plate collectors (Hayes, 1977). A more readily adaptive technology has been pioneered in Australia and the U.S.A. in the past five years; evacuated tube solar collectors. Scientists at Sydney University have developed prototypes of this technology which can achieve a continuous flow of steam at  $200^\circ\text{C}$ , and with a stagnation temperature of  $300^\circ\text{C}$  (SEG, 1977). This research parallels development by the Owens-Illinois Co. in the United States. The ACI (Australian Consolidated Industries) glass manufacturers in Lae have a technical agreement with the parent company of Owens-Illinois (Corning U.S.A.) and will be able to produce evacuated glass tubes in Papua New Guinea should a market develop. In 1977 the Sydney University Solar Energy Study Group received a research grant of A\$5 million from Saudi Arabian sources to develop their version of this technology. Discussions with the research team (Dr. Brian Window) have led to demonstration projects being mounted

in Papua New Guinea on air-conditioning and refrigeration using these evacuated tube collectors. Ten square metres of these collectors are in use on test rigs and attached to Yaziki commercial air-conditioning equipment with a modified chiller at the University of Technology in Lae this year. This technological option for alternative energy development must be regarded as viable in the medium term.

(c) Industrial steam raising and water heating (between 50°C and 150°C)

In the compilation of industrial energy use statistics the low grade heat requirements have been separated out, and have been shown to be 18% below 100°C, and 21% below 150°C. The upper end of the range of temperatures can be satisfied with the application of evacuated tube collectors which are capable of providing steam at 100 psi. It is clear, however, that significant capital costs would be incurred in the establishment of local plant to manufacture evacuated tube collectors, and that, despite the desirability of ultimately establishing a local Papua New Guinean production capacity, industrial end-uses are few which can only be satisfied by this solar technology, and not by refined flat plate collectors. The data presented indicate that the major users of low grade heat in industry, apart from the domestic end-use equivalents of electric hot water systems dealt with previously, are the brewers and the soft drink manufacturers. In these industries, end-use temperatures of between 55°C and 65°C are required for washing containers, and warming and pasteurising the beverages. In the brewing industry it is estimated that at least  $250 \times 10^5$  MJ could be replaced by solar heating, given a solar contribution of 60% to 75% of the energy demand for low grade end-uses. By similar criteria about  $30 \times 10^5$  MJ of the low grade could be satisfied by solar radiation. These estimates allow for 25% to 40% of the end-use requirements being satisfied by

conventional back-up boiler facilities, fired by imported oils or locally available renewable fuels. Data are presented in Table 18 and Figures 10 & 11 which indicate that solar radiation over Lae averaged  $18.8 \text{ MJ/m}^2$  per day for the period 1974 to 1977, and that for the months May, June, July and August, the monthly average falls below the annual average insolation. It is only during the months of July and August, which correspond to the peak of the wet season, that the insolation drops to less than half the average daily level for the year for six to ten days. Under normal circumstances it would be during these months that the back-up facilities would need to be used to their maximum. The relative costs of solar energy and back-up energy forms in storage facilities in relation to the average insolation for Lae will be the key determinants of the economic status of using direct solar radiation for either heating, or on site electricity generation in Lae.

Some indication of the costs of solar heating in industry can be obtained from experiments currently being conducted in industry in Melbourne, Australia, by the CSIRO Solar Energies Study Unit. Two collectors were tested in a raise mounted on the factory of Coca Cola Bottlers in Queanbeyan, New South Wales. The conventional collector type has standard window glass, double glazed, and the collector has a copper oxide selective surface. New collectors were tested which markedly increased the amount of energy transmitted to the collector. These have a single pane of low iron glass, currently imported from Belgium, and a chrome black selective surface. Both of these collector modes could be constructed, under licence, with the existing fabrication facilities in Lae. The cost performance of this first attempt at industrial water heating in Australia was expressed as  $5 \times 10^3 \text{ MJ}$  saved per \$1,000 (1977 Dollars) invested (Morse, 1978). If this technical improvement is matched by an increase in the price of distillate to world parity level, a move which must be anticipated during the 1980's, then a gross return of

TABLE 18 : ENERGY POTENTIAL OF LOCALLY AVAILABLE RENEWABLE ENERGY  
 SOURCES OTHER THAN FOR INDUSTRIAL AND COMMERCIAL END-USES  
 (MJ x 10<sup>5</sup>)

Energy Source	Hydro-electricity*** Near Term - to end of 1980	Medium Term - 1985	Long Term - by 2000
Agricultural residues (coffee husks)	29	43	89
Cardboard	176	260	541
Paper	12	18	37
Waste oil		200	416
Tyres			104
Wood waste - co-generation pyrolysis	111 1013	10,093*	18,300†
Solar - 50°C	15 (75 substitution for renewable hydro-electricity)	90	180(est)
50°C - 150°C		280	560(est)
Air conditioning and refrigeration		(180 substitution for renewable hydro-electricity)	
Electricity, from photovoltaic cells			(very large)
Totals	1356	10,984	20,227

Combined Industrial/Commercial Energy Demand, 1976-77, excluding transport = 5543.37  
 Combined Industrial/Commercial Energy Demand, 1976-77, non-renewable only = 4103.11  
 Energy Sources Available for Industrial/Commercial End-uses - 1090.

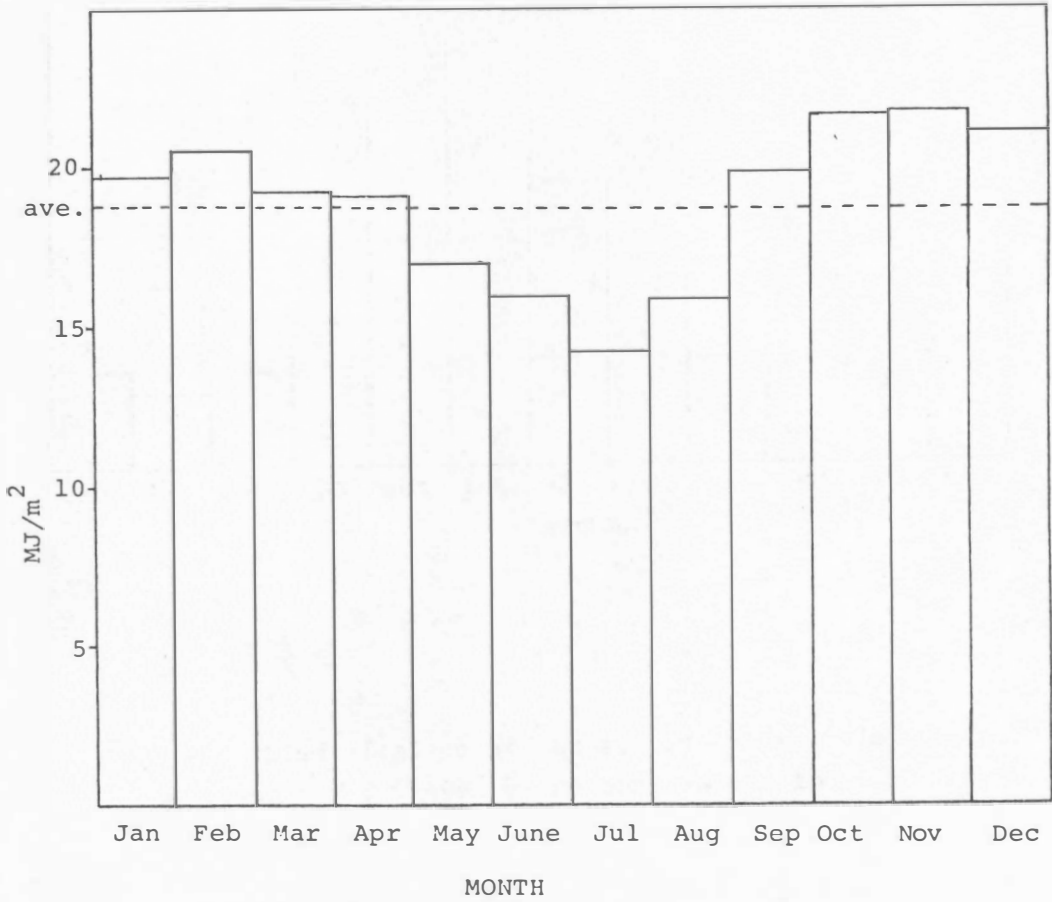
\*Includes utilization of 400 x 10<sup>5</sup> MJ off-gas for in-plant electricity generation at SPT, Lae.

†A minimum figure for sustainable yield of pyrolytic fuels. This way not all will be used for industry for by then ethanol production from wood-waste will be economic at the 200 ODT/day production level.

\*\*Wastes other than wood residues are assumed to escalate in volume at 5% per annum in line with anticipated industrial production.

\*\*\* Hydro-electricity is assumed to be developed at a sufficient rate in the hinterland to meet a 5% per annum growth rate in industrial demand.

Figure 10 Total Radiation on Horizontal Surface.  
Daily average X Month ( $\text{MJ}/\text{m}^2$ ).

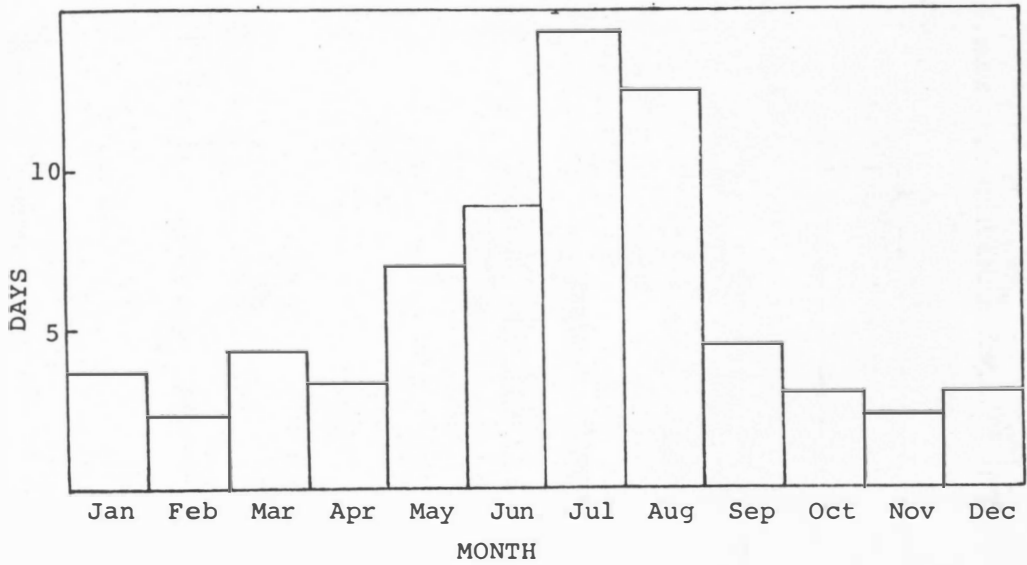


Source: C.S.I.R.O.

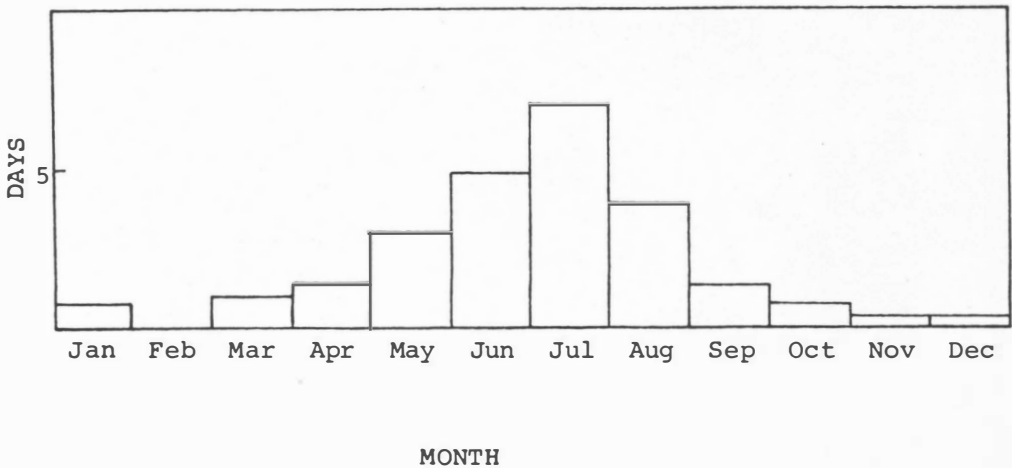


Figure 11 Total Radiation on Horizontal Surface

(a) Number of days radiation falls below 75% of the average daily level for the year.



(b) Number of days radiation falls below 50% of the average daily level for the year.



investment of about 15% can be expected. The CSIRO is now setting up demonstration facilities in a South Australian brewery, and in a commercial dairy. Their experience has been offered to the Department of Minerals and Energy to establish similar demonstration facilities in Papua New Guinea. From the foregoing, it appears likely that solar heat to 70°C for industrial processes will be viable in Papua New Guinea in the medium term, perhaps during the 1980's.

(d) Solar electricity

Here we are dealing with two distinct technologies; photovoltaic cells and solar turbines. Both are appropriate for consideration for the near term in respect of supplying electricity to isolated rural areas which have no hydroelectric resources.

Photovoltaic cells are solid state semiconductor devices which release electrons and generate electricity when bombarded by the light energy of the sun. The three most promising types of cell are improved versions of crystalline silicon cells already marketed, the CdS, Gas and other thin film sandwiches marketed in the United States and under development in many versions throughout the world, and the amorphous silicon cells of various types. PVC's made of silicon are expected eventually to have maintenance free lives of 20 years. Early problems of water ingress in PVC's tested in Papua New Guinea indicate that more development work must be carried out before they can live up to these expectations.

In 1978 reports were released which predicted that photovoltaic cells could generate electricity for an installed cost of US\$500 per kilowatt average, or less, by 1985 (OTA, 1978; Kelly, 1978; Orvshinsky, 1978). It was also believed possible to reduce costs to US\$1000 to US\$200 per peak kW by 1983, which means producing electricity for 7t to 30t per kilowatt hour.

It is now believed that the remote but populous rural communities of the developing countries will constitute the medium-sized market that is necessary to ensure a relatively risk-free

progression in production capacity, up from serving the remote unmanned generation demand in the developed countries, and towards competing directly with other alternatives there for the 10 to 100MW new installation market (Wolf, 1977). Certainly there is some substance in this belief for the costs of electricity from diesel generation in outlying areas in Papua New Guinea, at the 10-50 kW demand level, are now frequently between US\$1.00-1.50 per kW hour.

In the U.S.A. in 1977 the cost of diesel-electric was about US\$0.20kWhr. at a capacity factor of 0.11, and the most sensitive of demand curve array price projections showed that demand for PVC's would be slow and that significant penetration into the 10-1000kW diesel generation market would not occur until after 1982 (Wolf, 1977). If in the meantime oil prices have increased 80%, and even before this, significant markets at this level of application existed in developing countries, such as Papua New Guinea, where generating costs 2 to 10 times higher than the above stated U.S. data prevailed. Here, then, enterprising companies should be able to achieve a steady market growth through gradual price reductions.

While this market potential is undoubtedly perceived by some of the PVC producers in the U.S.A., there has been little indication in the market place of falling prices to consumers in the South Pacific. While the costs of PVC's exceed US\$10,000/installed kW in the U.S. in May 1978, prices quoted to dealers in Papua New Guinea, f.a.b. the East Coast of the U.S.A. were effectively US\$24,000/kW for small household units. Even so sales of PVC's in Papua New Guinea have been considerable and are growing rapidly. Indeed we believe that even at this price they may be competitive, on the basis of cost per lumen delivered, with kerosene lamps in peri-urban and rural environments, taken over a five year period (D.C.F. on hardware and recurrent expenditure during the guarantee period for PVC's and battery).

There are additional great incentives for Papua New Guinea to examine the utility of PVC's for they offer a durable, convivial and reliable source of electricity in units small enough to provide for end-uses for which electricity is the best, or only viable energy source. In that sense they are directly compatible with a national development strategy that emphasises rural development based on self-sufficient communities and small-holder industries. For this reason,

tenders will be called by the Department of Minerals and Energy in 1980 for demonstration 10kW (nominally) arrays at suitable remote sites, and the cultural compatibility and economic performance of this source is being carefully scrutinized in several schools and community centres.

### Conservation

A great part of the potential for energy conservation has already been indicated in the section on alternative energy sources which deals with the use of waste materials as an energy source. There, it is suggested that minor modifications to existing industrial plant will enable renewable energy resources, perhaps already on-site, to be utilised and energy imported from outside the factories to be conserved.

The amount of energy that may be conserved by increasing the efficiency of the physical plant, i.e. the amount of produce per unit energy input, has not been estimated in this research in a technical sense, although the possible savings can be estimated by assessing current attention to energy use by factory managers. The first component of an energy conservation strategy for an industry must be a detailed knowledge of the energy intensity of a particular in-plant process. This should, theoretically, lead to cost-effective allocations of available capital and expertise to the reduction of energy use, providing adequate information on the ways in which savings can be made is available. Only two companies, one concerned with glass manufacturing and the other with brewing, systematically monitored energy use and were able to produce data on the energy savings of modifying in-plant processes in specified ways. Given that these companies utilise close to half the total energy flow in the industrial sector, it is not surprising that their data on energy use are of above average standard. The brewery maintains the most comprehensive data set on factory end-use. Technical staff compile and contrast monthly data on energy use per hectalitre of beer processed, with special attention being given to the energy intensive components of beer manufacturing which are the heating and cooling processes. These are compared also with international

standards of energy efficiency for these processes set out by the parent company, Heineken of Holland.

Through discussions with management, the level of knowledge of energy use in the factory and the individual's perception of the need to conserve energy was able to be gauged. Generally, industrialists replied either that they were concerned to conserve energy but that they had little information about effective monitoring procedures and alternatives to present modes of operation, or that they had not considered the question seriously. It is worth reiterating that most companies operating in Lae are Australian-based and have developed and are maintaining their present patterns of operation in the context of petroleum fuels priced at between 25% and 50% of the world parity price (up until 1978) and with electricity costs at less than one-quarter those applying to industry in Papua New Guinea. Presumably, in time, each energy intensive industry or any industry in Papua New Guinea that, for example, operates boiler equipment, will come to recognise the savings that can be made through better management, and with more energy efficient equipment. However, unless stimulated by Government intervention, this learning process may well be unnecessarily slow. The savings that can stem from better management are likely to be significant. For the U.S.A., it has been suggested that merely improved 'housekeeping', including no changes in capital equipment, can save 13% of total industrial energy use (Ross and Williams, 1977). Again, in an examination of boiler efficiency in the biggest industry in Hong Kong - the textile manufacturing industry - even the companies which boasted good boiler management were found to be able to save 20% of energy use by simple adjustments, and continuous monitoring of boiler equipment (Newcombe, 1975). Thus, it is not unreasonable to expect, for industry in Papua New Guinea, that by merely improving the energy management of existing equipment, the industrial and commercial energy demand can be reduced by 10% to 20%. This potential has been confirmed by a recent consultancy by the Conservation and Renewable Energy branch of the Canadian Department of Mines and Resources for the DME, PNG (Walterson, 1980).

Another important area for energy conservation is through co-generation of low-grade heat and electricity. Here we are not implying the sale of electricity back to the grid, but rather, a better and thermodynamically sensitive management of present energy usage. The diesel or fuel oil now burnt directly can be used to generate electricity, and waste heat, upgraded where necessary, can be used for the heating applications which were previously the only end-use. The potential of co-generation is very considerable, amounting to a reduction of 25% in industrial electricity demand from co-generation systems that have already been identified, and accepted by industry to the end of 1978. This includes timber industries utilizing their wastes for both electricity and steam generation. Although this 25% electricity demand reduction represents only 4% of total industrial fuel use, it is the most expensive component, being, at its cheapest, 3 times more per MJ than the most expensive imported petroleum fuels. In addition, the hydro-electric scheme from which Lae draws its power, the Ramu Scheme, is fast nearing capacity, and back-up gas turbines burning distillate are now contemplated. In this situation any reduction in electricity demand to allow time for engineering the supply of more hydro-power is highly desirable.

This brings forward another critical area of energy conservation which is completely untouched at present, that of matching the size of the industrial electric motive power equipment and the size of the demand. When the capacity of the electricity supply system is being stretched to the limit, and the marginal costs of production are higher than the average costs, as in Papua New Guinea, any unwarranted increase in maximum demand is a severe burden on forward planning and development capital, and is ultimately reflected in higher costs to the consumer. In the United Kingdom, where industrial planning is surely no less sensitive in this area than in Papua New Guinea, it has been found that about 50% of the electricity intake is unnecessarily dissipated in the transformation to final motive power because of greatly oversized equipment for the tasks performed (Murgatroyd and Wilkins, 1977). It is completely reasonable, then to have a one-off reduction in electricity demand, over the next 3-5 years of 30-40%, and to be able to bring industrial

load growth down by careful forward planning thereafter. This could be achieved with significant economic gains to both industry and Government and raises the question of the kind of policy initiatives necessary to achieve these goals.

### Discussion

This research has enabled an evaluation to be made of the range of alternative energy sources available within and around the Lae urban area and of their importance in terms of their contribution to industrial/commercial energy supply in the foreseeable future. Table 5 lists these energy sources, leaving out hydro-electricity and indicates for 1980, 1985 and 2000, the volumes that can be economically brought-on-line in terms of our present understanding of the respective energy conversion technologies. Hydro-electricity, and other renewable energy sources currently in use, are assumed to grow sufficiently in availability to meet their current share of total industrial/commercial energy use, i.e. 22%, up until the year 2000. Although no time-series of industrial/commercial demands for Lae are available, estimates made in this research of the growth in national energy demand over the past 4 years, show a 5% per annum compound growth rate in industrial/commercial energy use and seem a reasonable reference growth rate by which to measure the future adequacy of alternative energy sources that are identifiable now. Factory wastes and waste sump oil are also assumed to grow in volume in proportion to industrial/commercial energy use, i.e. at 5% per annum.

Under this simplified scenario, total industrial/commercial energy use will approximate  $6200 \times 10^5$  MJ in 1980,  $7895 \times 10^5$  MJ in 1985, and  $16,410 \times 10^5$  in 2000. If the 1977 ratio of 73:27, non-renewable to renewable forms were maintained throughout the aforementioned period, non-renewable energy sources or imported petroleum product demand would be about  $4525 \times 10^5$  MJ in 1980,  $5760 \times 10^5$  MJ in 1985, and  $11,980 \times 10^5$  MJ in 2000. Therefore, by 1980, 30% of imported petroleum products could be replaced by alternative energy sources, making renewable energy sources 49% of the total energy supply to the industrial and commercial sectors. By 1985 there is

almost double the more economically competitive energy available from renewable sources than is needed to meet total commercial/ industrial demand at that time. By the 1990's it will be economic to harvest the forest wastes within a 30km average haul. This resource is huge and even with the most conservative of estimates of harvesting it on a 30 year rotation, an additional  $8200 \times 10^5$  MJ in the form of char and oil become available, boosting the renewable energy resource to 1.7 times the year 2000 demand, which is, at least, 3 times the 1977 demand level. It is conceivable, however, that a significant proportion of this waste wood will be converted to methanol for transport fuels, a matter which is discussed in the transport papers (Newcombe, et al., 1978).

Whilst there are renewable energy sources available which can economically compete with all the existing end-uses of imported petroleum products in industry and which have the potential to totally substitute for these imports by 1985, it will require a great deal of enthusiastic experimentation and application of appropriate end-use technology by industry for this to happen. It will be recalled that the bulk of petroleum fuels are used for raw heat or steam raising, and that the existing end-use equipment is designed for the combustion of fuel-oils and diesel for these purposes. Modifications to equipment and fuel systems will have to be made to allow for the storage, blending and firing of charcoal-oil mixtures during the life of the present combustion equipment. The sole use of pyrolytic fuels, either char for gasification or powdered fuel firing; char-pyrolytic oil mixtures, or pyrolytic oil straight or blended, and perhaps off-gases, will have to await suitable modifications or the installation of powdered fuel systems, dual-fuel boilers, or front end gasification units. Rather, if all new industry and new combustion equipment can use pyrolytic fuels, then 55% of industrial heat raising will be from pyrolytic fuels and 45% from imported petroleum products by this time. If, in the interim, existing industry is given the economic incentive to use pyrolytic fuels, by marketing them initially at a discount below the price of fuel oil, which is the cheapest imported energy form, then there could be either a complete change in, or major modifications to, existing combustion equipment before the end of its useful life to enable the combustion of wastes



or pyrolytic fuels. Should as many of the industries as would constitute half of the existing industrial/commercial end-users make this transition, then by 1985, 80% of heat-raising will be from renewable resources, and 85% of total industrial/commercial end-use could be from renewable energy sources.

At this time the modification of existing industrial combustion equipment to utilise pyrolytic fuels does not appear technically difficult or prohibitively expensive. Once appropriate modifications to existing equipment, or suitable off-the-shelf technology has been demonstrated, then the price of the alternatives will tend to dictate the rate at which they will substitute for conventional petroleum fuels in the marketplace. It is already clear that the relative price of alternative fuels is highly favourable for a rapid transition to take place. Table 1 shows the relative effective price in 1977 of energy forms which can be used for heat-raising in industry. A comparison of prices at end-use will also serve to clarify the relative value of hydro-electricity for this purpose, for there is a considerable misconception amongst the public that hydro-power is not only the best, but the cheapest alternative energy source for all end-use currently performed by imported petroleum products. In fact, hydro-electricity, when used for heat or steam raising, is effectively 5 times more expensive than is pyrolytic fuels, even allowing for a 30-50% rate of return for pyrolytic fuels, and only a 10% rate of return on hydro-power at these prices (Table 1). The direct combustion of wood residues is cheaper than electricity even taking into account the capital costs of end-use equipment.

Having determined that the economic incentive to switch to fuels based on renewable forest energy is very great, and that there is technical know-how to exploit them, there appears to be no reason to doubt that the almost total substitution of imported petroleum products by pyrolytic and other wood fuels for heat raising can occur by the year 2000.

The other transition that will be made during the next decade to 15 years is a substitution of one renewable energy form for another; that of solar heating and cooling for hydro-electricity. This transition will be based on economic, social and strategic considerations.

Whilst hydro-electricity is a renewable energy source, the costs of extracting it are comparatively high under Papua New Guinean geological and climatic conditions. The construction and maintenance of hydro-headwater generating and transmission systems requires a level and range of skills not now available within the country so that this pattern of electricity development will be more expensive in Papua New Guinea than in developed countries even considering that in the longer term conservation of energy is just as important under a renewable energy regime.

Firstly, any potential excess of supply over demand for renewable energy for the industrial/commercial sector will not be a real excess because there are ways of using these energy forms profitably in both the transport and domestic sectors, and the export of some fractions of the alternative energy stream to nearby ports and demand centres is being contemplated. Secondly, the supply of these renewable energy forms from readily accessible sources is ultimately limited, and both may show marked increases in the marginal cost of production, economically and ecologically. Therefore wise use of these resources in terms of their most efficient thermo-dynamically appropriate end-uses will both reduce the average cost to consumers, and effectively increase the size of the resource.

The value of conservation is now especially clear in respect of the supply of hydro-power to Lae from the Ramu system of 30MW. The 1979 demand was 24MW peak, and given reserves, and anticipated near-term load growth, is close to its maximum capacity. Diesel powered gas-turbines are being planned to alleviate the problem, but in fact they will aggravate the general problem of increasing reliance on imported petroleum products. We have shown that at least 25% of Lae's industrial electricity demand could be met by co-generation and alternative energy sources with reduced cost and environmental impact. If due regard for a comprehensive overview in energy planning, and for thermodynamic considerations in the microcosm of every industrial activity had been made these options would automatically have been taken up. Finally, it must become possible to readily assess the impact of the kind of energy initiatives here presented on the total pattern of energy use in the Papua New Guinean economy. This means simple, fast, and effective data collection and analysis has to be

established with the direct and willing co-operation of the business community. Annual censuses of energy use, industry by industry, end-use by end-use, and region by region, are critical to effective energy planning and energy development. These have been instituted by the Department of Minerals and Energy as of 1979.

### Summary

The research documented here was conducted between August 1977 and May 1978. From the beginning of 1978 close co-operation was arranged between the UN Research Team and the Department of Minerals and Energy, Port Moresby. This co-operation had, by the end of 1978, led to the adoption of most of the policy options outlined, and to the investigation of the alternative energy sources in proportion to their importance to future energy supply (Newcombe and Weick, 1978).

Although the initial research concentrated on the energy flow in Lae and between Lae and its hinterland, it was hoped that the alternative energy sources and the management and planning modes that were identified from this work would be applicable to Papua New Guinea as a whole. This now seems to have been a reasonable aspiration. In respect of Lae itself, the data and analysis presented here, suggest it to be possible for renewable energy sources to contribute 49% of the 1980 demand, 85% of the 1985 demand and all of the year 2000 demand for industrial/commercial energy.

Whilst Lae is especially advantaged because of its proximity to extensive forest resources, this does not make it exceptional in the context of the nation. For example, we have found that for Papua New Guinea as a whole, existing forestry wastes, both in the forests and at the sawmill, are equivalent at a minimum to the total of petroleum imports.

Chapter 4

Energy for Transportation

Revised from "The Transport Papers" by Ken Newcombe, Kaye Bowman and James Pokris. PNGE/T5, CRES, Australian National University, Canberra. December 1978, 72pp.

The following analysis of the transport sector in Lae is comprised of two sets of data; one, an overview of the end-use within the sector and, two, a detailed assessment of the present pattern of traffic around and within the Lae urban area.

The implications of these analyses are discussed in respect of policy options designed to reduce transport energy demand, conserve transport energy and to provide, in the long term, for significant substitution of imported transport fuels with locally produced renewable energy forms.

#### Orientation of the research

An important value premise upon which this research is based is that the transport needs of low income groups be a prime concern. Transport systems for the needy must guarantee access, at low cost and high convenience, to the subsistence requirements of life in the given setting, including essential materials such as food, energy and water and information sources and services such as education, health, entertainment and recreation. Of even greater importance is that they be sympathetic with the culturally and biologically determined requirements for human wellbeing in the specified population.

As a whole, the transport system must, in terms of its inputs and its design, be compatible with maximum self reliance and with currently emerging economic and ecological constraints.

This research is concerned with the nature of the development which present transport systems are fostering or of which they are representative.

#### The vehicular transport network of Lae

Lae is the second largest urban centre and foremost industrial town of Papua New Guinea. The population is estimated to be 45,000 made up of 41,000 nationals and 4,000 expatriates. The population growth rate of this urban area is 5% per annum. The vast majority of the new settlers swell the numbers for self-help and temporary accommodation in formal and informal settlements at the urban fringe.

Up to now there has been an active programme, undertaken particularly by the National Housing Commission, to shift settlers into formal or planned settlement areas with basic services such as drains, pit latrines, community water supply and roads.

As one might anticipate, Lae is designed along conventional Australian town planning lines. There is a central business district surrounded by the oldest of the high covenant housing which includes some blocks of flats. Generally, high covenant houses are placed on 0.1ha. blocks, or larger, in regular rows dissected by full sized suburban vehicular roads. This pattern extends for about a two mile radius and includes an industrial area where the design is similar but more extensive. Beyond the inner core of high covenant housing, single lane roads lead out to low income settlements and to institutions, such as the University of Technology, which contain the full range of housing forms. In the low income settlements the town planning design is the same, but in miniature form. The exceptions are the informal or unplanned settlements where housing allotments are irregular in size or even undefined. In these areas, gardens dot the interstices between the houses and the footpaths which lead off a few entrance roads and ramify throughout the settlements into the hills behind.

Lae is serviced by regular shipping, aircraft and road transport services. It is a major port for export and import cargo and the focal point at the end of the country's single major highway system which penetrates nearly 560 kms back into the Highlands and which now links with the other major coastal port of Madang.

This situation is illustrated in Figure 12 where air, sea and road transport services are indicated. Complementary data for road transport on the Highlands Highway out of Lae are provided in Table 1.

Aircraft movements at Nadzab Airport (Lae's main airport) comprise F27 and F28 propeller and turbo jets of Air Nuigini, carrying passengers and cargo directly to and from other major Papua New Guinea towns. The light aircraft movements out of Lae airport compete on some of the Air Nuigini routes but mostly service the many isolated missions and villages in the rugged terrain of the Morobe Province in which Lae is situated.

Coastal shipping in vessels of up to 10,000 tonnes move imported cargo out to other major coastal towns and villages. Larger

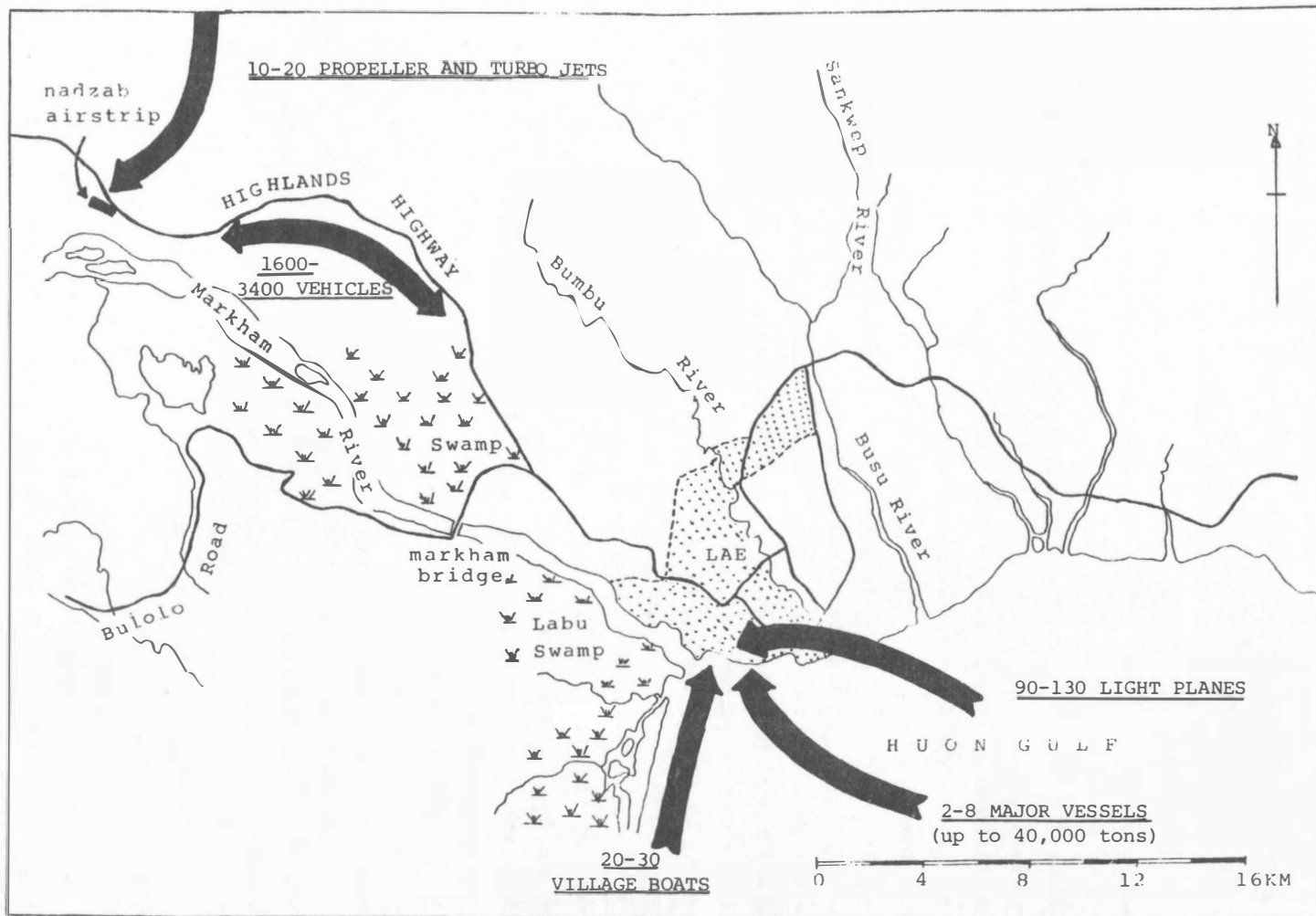


Figure 12 Daily traffic movements in and around Lae.

capacity vessels (40,000 tonnes) deliver imports to and take exports from Lae to European, Asian and Oceanic ports. These larger vessels make infrequent visits to Lae compared with a daily procession of at least twenty village launches ferrying people and small cargo to and from villages on the Huon Gulf and beyond.

The Highlands Highway is the only road to the Papua New Guinea Highlands. The two other main roads lead 40km towards Finschafen in the east and 140km to Wau and Bulolo in the west. The 1975/77 data of traffic flow to and from the highlands, as shown in Table 19a indicate a progressive buildup of traffic, although the cargo component of this traffic varies greatly throughout each year (see Table 19b). This seasonal variation is strongly influenced by the coffee cropping cycle. For instance, in 1976, several times more coffee was moved to Lae than for other recorded periods, with a corresponding nearly threefold increase in fuel and a ninefold increase in the store items carried to the highlands.

#### Vehicle stocks

Obviously the number of vehicles in use bears a fairly direct relationship to total transport energy use, even though changes in energetic efficiency of the vehicle stock can greatly influence ultimate end use of transport fuels. In Papua New Guinea, little influence, other than price, has so far been brought to bear on the energetic efficiency of transport modes. Data presented in Figures 13 and 14 show a time series of registrations of vehicles by type over the past decade. Between 1965 and 1972 total vehicle numbers rose at almost 15% per annum, and by 2.5% thereafter. The early growth rate is maintained for commercial vehicle registrations, even though between 1972 and 1976 private car registrations have been falling at the rate of 4% per annum.

In Figure 14 Papua New Guinea ownership of vehicles has been separated from European ownership. A significant part of the fall in private car registrations during the 1972 and 1976 period seems to be explained by the fact that private car ownership is dominated by Europeans, and that their overall number in Papua New Guinea fell significantly during this period, but now appears to be levelling off.



TABLE 19a VEHICLE AND PASSENGER MOVEMENTS ALONG HIGHLANDS HIGHWAY TO AND FROM LAE OVER A ONE WEEK PERIOD

(1975-77) \*

Vehicle type	<u>1975 (Aug/Sept)</u>				<u>1976 (Sept)</u>				<u>1977 (July)</u>	<u>1977 (Dec)</u>	
	Total Vehicles	% of Total	Total Passengers	% of Total	Total Vehicles	% of Total	Total Passengers	% of Total	Total Vehicles	Total Vehicles	% of Total
Car	2069	30.0	4299	14.0	2039	22.4	4822	10.8	) 5229	4296	28.0
Utility	1261	18.2	3796	12.3	1875	20.5	5901	13.3		)	4476
PMV	1363	19.8	15554	50.6	2191	24.0	24628	55.4	) 2522	3095	20.2
L. Truck	639	9.3	2428	7.9	960	10.5	4475	10.1		)	1968
H. Truck	879	12.8	2197	7.1	1225	13.4	3188	7.2	2157	1292	8.4
Other	683	9.9	2479	8.1	831	9.2	1404	3.2	1299	221	1.4
<b>Total</b>	<b>6894</b>	<b>100.0</b>	<b>30753</b>	<b>100.0</b>	<b>9121</b>	<b>100.0</b>	<b>44418</b>	<b>100.0</b>	<b>11207</b>	<b>15348</b>	<b>100.0</b>

\*Data were collected at the Lae weighbridge during the full 24 hours of each day.

TABLE 19b FREIGHT MOVEMENTS ALONG HIGHLANDS HIGHWAY TO AND FROM LAE

Commodity	1975 (Aug/Sept)		1976 (Sept)		1977 (July)	
	1 Week Total (tonnes)	% of Total	Tonnes Total for week	% of Total	Tonnes Total for week	% of Total
Fuel*	957.7	16.6	2337.6	16.8	988.5	20.0
Empty fuel drums+	18.8	0.3			2.0	-
Coffee+	1047.5	18.2	2509.8	18.1	702.4	14.2
Tea+	62.4	1.1	118.4	0.1	93.0	1.9
Cocoa+	50.7	0.9	129.0	0.9		
Livestock+	55.0	0.9	105.5	0.7		
Timber (Sawn, Logs, plywood)+	826.8	14.4	1793.3	12.9	382.0	7.7
Vegetables+	131.0	2.3	228.1	1.6	9.0	0.2
Building materials*	205.9	3.6	285.6	2.0	101.0	2.0
Machinery*	250.0	4.3	95.0	0.7	11.0	0.2
Gravel	98.5	1.7	355.8	2.6		
Store items*	320.9	5.6	2832.9	20.4	245.5	5.0
Beer					140.7	2.8
Empty bottles					4.0	-
General	1724.4	30.1	3102.4	23.2	2276.3	46.0
<b>Total</b>	<b>5749.6</b>	<b>100.0</b>	<b>13893.4</b>	<b>100.0</b>	<b>4943.72</b>	<b>100.0</b>

+ It can be assumed that these items are moving into Lae and items marked \* are moving out of Lae.

Source: Highlands Highway Traffic Survey, Office of Transport, Information Bulletins No.22, 26, 27.

Figure 13 Registered Motor Vehicles by Type in P.N.G.

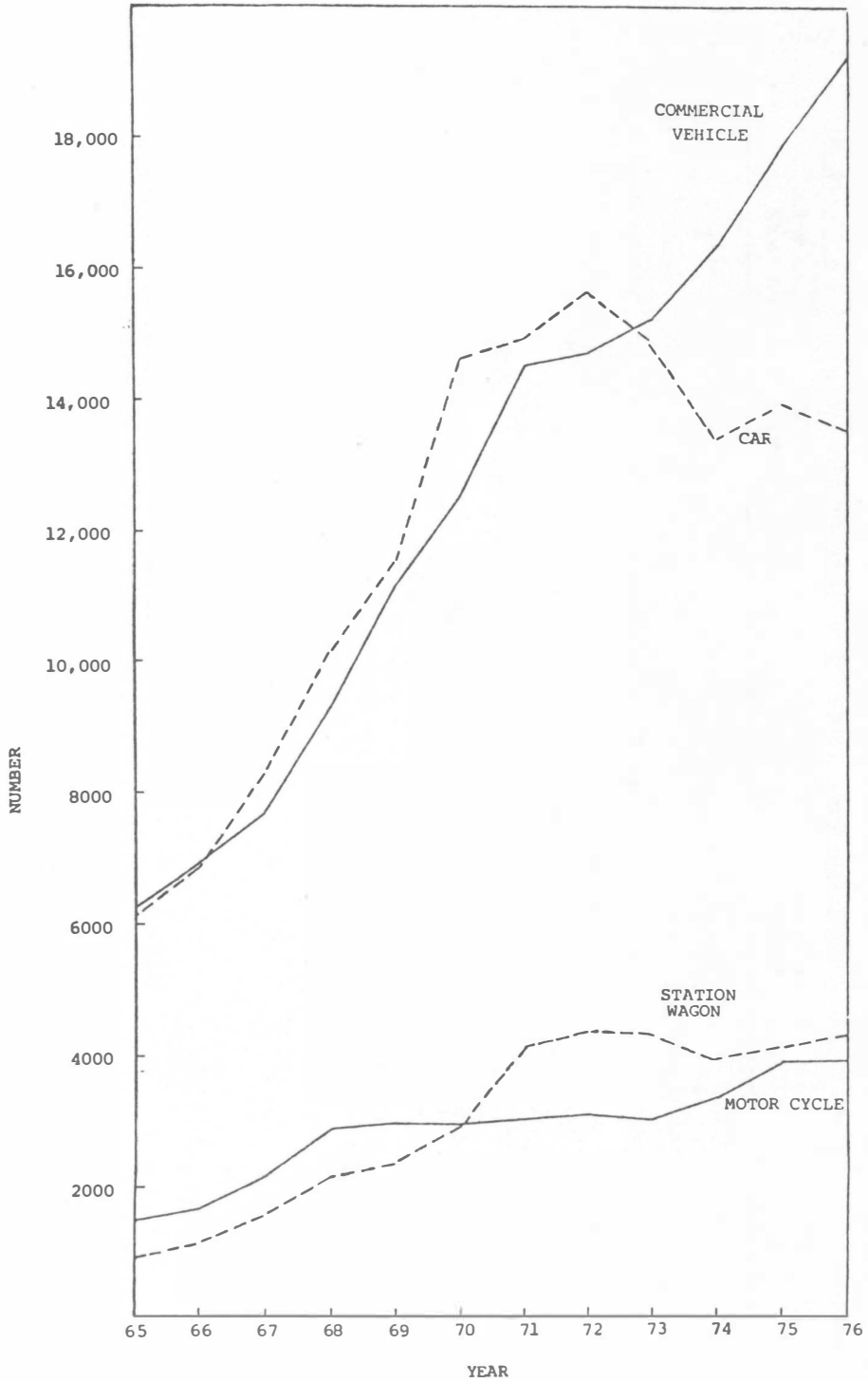
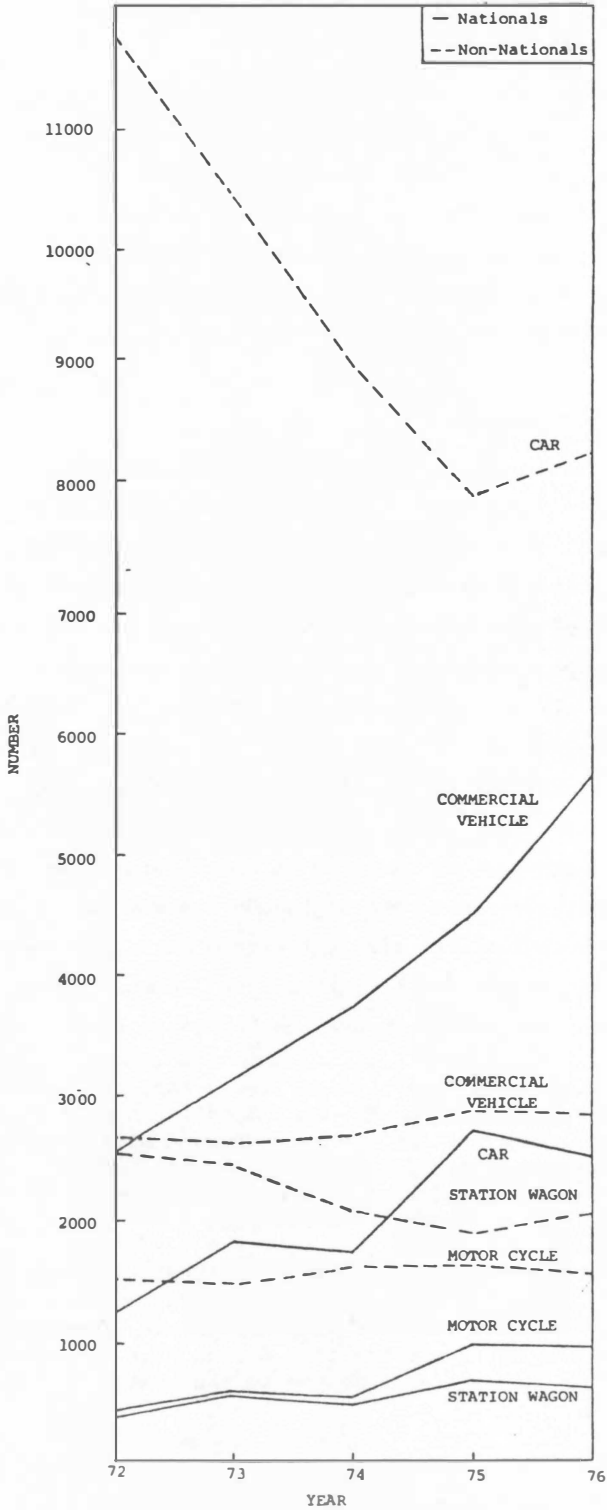


Figure 14 Registered Motor Vehicles Owned by Private Persons by Vehicle Type in P.N.G.



In the same period the Papua New Guinean ownership of private cars has about doubled; but there is a recent decline in the number of vehicles registered by Papua New Guineans, which may reflect rising costs of petroleum and vehicle maintenance.

On the other hand, ownership by Papua New Guineans of commercial vehicles on a country-wide basis has more than doubled during this four year period (the only period for which Papua New Guinean vis a vis European vehicle ownership data are available) and the trend shows no sign of abating. It can be speculated that this trend is dependant on good prices for cash cropping in the rural areas and sustained growth in the demand for public motor vehicles.

#### Transport energy use in Lae

For the moment we will concern ourselves with commercial extrasomatic energy<sup>1</sup> forms only. This means that the data presented in this section will deal with motor spirit<sup>2</sup>, distillate, aviation turbine fuel and aviation gasoline. In the overview papers of the Energy Policy Project (Newcombe, 1979) we establish the end use of energy in the transport sector in Lae which, when counting all energy use by vehicles in all sectors of economic activity (de facto the convention), represents 31% of total energy use excluding bunker fuels, or 58% including bunker fuels. To clarify, we mean by bunker fuels, in the context of Lae, that energy which is acquired and stored for shipping servicing the port of Lae, for aircraft refuelling in Lae, and for trucks hauling cargo on the Highlands Highway out of Lae. By excluding these bunker fuels we are left with a better estimate of transport energy use within the Lae urban area<sup>3</sup>, acknowledging, of course, that of the vehicles which use the Highlands Highway as much

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<sup>1</sup>Somatic energy: "That energy which is utilised, through the metabolic processes, within a living organism". Extrasomatic energy: "That energy which flows through or is utilised by a human community and which is not utilised through metabolic processes within a living organism."

<sup>2</sup>Motor spirit is frequently referred to as petrol or benzene; distillate as diesel; aviation gas as 'avgas' and aviation turbine fuel as 'avtur' or jet A1.

<sup>3</sup>For the purposes of the Papua New Guinea Human Ecology Programme the Lae urban area is defined so as to include the area confined by the Busu River to the west, the furthest boundary of the Igam Barracks compound across to the Swiss mission in a direct line to the north and the Markham River to the east and the sea to the south.

as 80% by number are public motor vehicles, private cars and utilities.

The energy costs of maintaining the inputs to Lae which provide for its economic and biological survival are reflected in the size of its bunker fuel consumption, and with bunker fuels at 27% of total energy use, these are clearly significant.

Table 20 presents the energy use by vehicle type for Lae during the study period from July 1976 to June 1977. Bunker fuels are incorporated in this table. Of total transport energy use, road transport dominates with nearly three-quarters of the total, with the other two categories of air transport and marine transport having a one-sixth and a one-tenth share respectively.

Within the road transport category, trucks for long distance haulage use the largest portion, 31% of the total. Roughly equal shares of about 20% are used by commercial and industrial vehicles, private motor vehicles and public motor vehicles. Road building uses about 9%, which includes fuels used by heavy machinery and Government vehicles utilise about 6% of total end-use.

In the air transport sector, light aeroplanes use more than half the energy and jets of the major airline, Air Nuigini, use 38% of the total.

The relative importance of each of the transport fuels in use is indicated in Figure 15, a pie diagram. Distillate fuels make up half and motor spirit one-third of total energy use by energy value (enthalpy).

#### Trends in transport energy use

If it can be assumed that the national trends in transport energy use apply to the population of Lae, which uses 10% of national transport energy, then from the national data presented in Figure 16, energy use in transport is increasing rapidly in the Lae urban area. In fact, on a national basis per capita energy use in the transport sector is increasing more rapidly than energy use in all other sectors. One complication with these data is that distillate fuels are an important industrial fuel, being used for boiler feedstocks in particular. However, the industrial end-use of distillate fuels for non-transport end uses is only one-quarter that for transport in Lae,

TABLE 20 ENERGY USE IN THE TRANSPORT SECTOR, LAE, JULY, 1976 - JUNE 1977

	Petrol	Diesel	Aviation Gasoline	Aviation Turbine Fuel	TOTAL	Internal Sector	Between Sector
<b>ROAD TRANSPORT</b>							
Trucks - Long Distance Haulage	314.29	2153.58			2467.87	30.6	
Buses	10.68	63.00			73.68	0.9	
Commercial & Industrial Vehicles (Including Company Cars)	798.45	905.91			1704.36	21.1	
Government Vehicles*	333.71	161.73			495.44	6.1	
Private Motor Cars & Bikes	1361.28				172.28	2.1	
Hire Cars	17.04				17.04	0.2	
Public Motor Vehicles	624.00	173.00			797.00	19.9	
Earth-Moving, Road Building Contractors	44.65	716.08			760.73	9.4	
Sub-Total	3677.02	4397.39			8074.37	100.0	73.0
<b>MARINE TRANSPORT</b>							
Shipping - Bunker fuels in Lae		993.73			993.73	94.3	
Private Pleasure Crafts & Launches	60.05				60.05	5.7	
Sub-Total	60.05	993.73			1053.28	100.0	9.5
<b>AIR TRANSPORT</b>							
Large Passenger & Cargo Planes (Including Jets) (Air Nuigini)				732.07	732.07	38.0	
Commercial Light Planes			926.85	57.88	984.37	51.1	
Government (including Army)			16.75	36.60	53.35	2.8	
Others			60.30	95.17	155.47	8.1	
Sub-Total					1925.62		17.4
<b>OVERALL TOTAL</b>	<b>3737.07</b>	<b>5391.08</b>	<b>1003.90</b>	<b>921.72</b>	<b>11053.77</b>		<b>100.0</b>

\*See additional Table.

Figure 15    Transport Sector: Energy Use by Fuel Type.

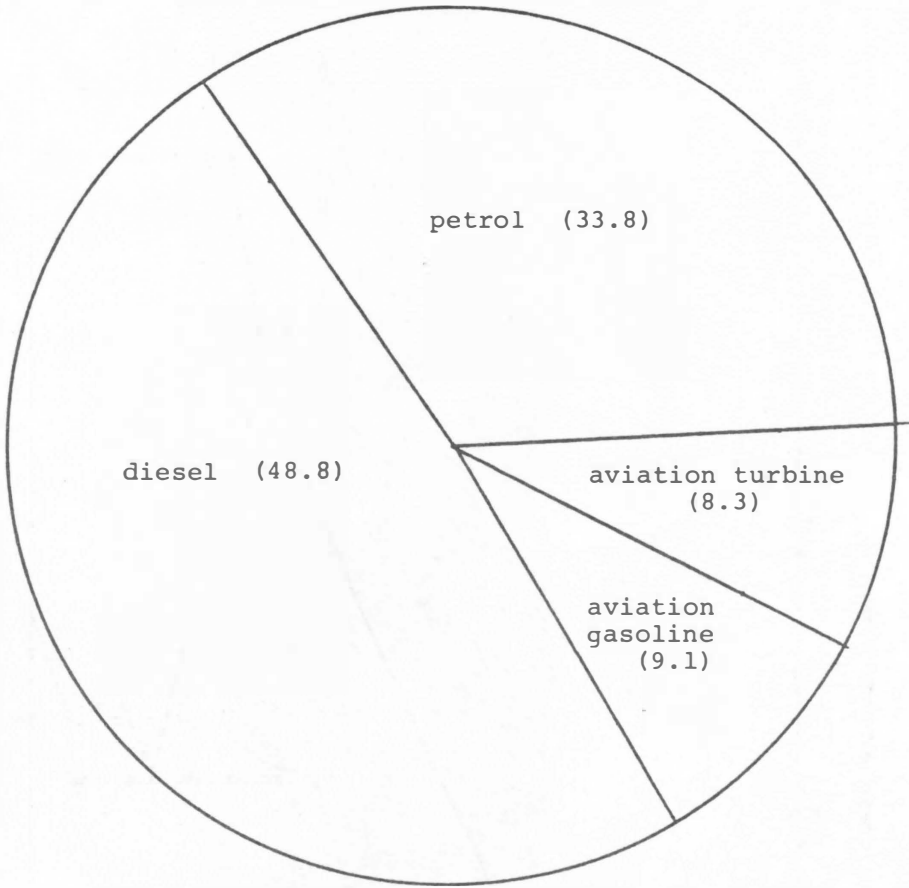
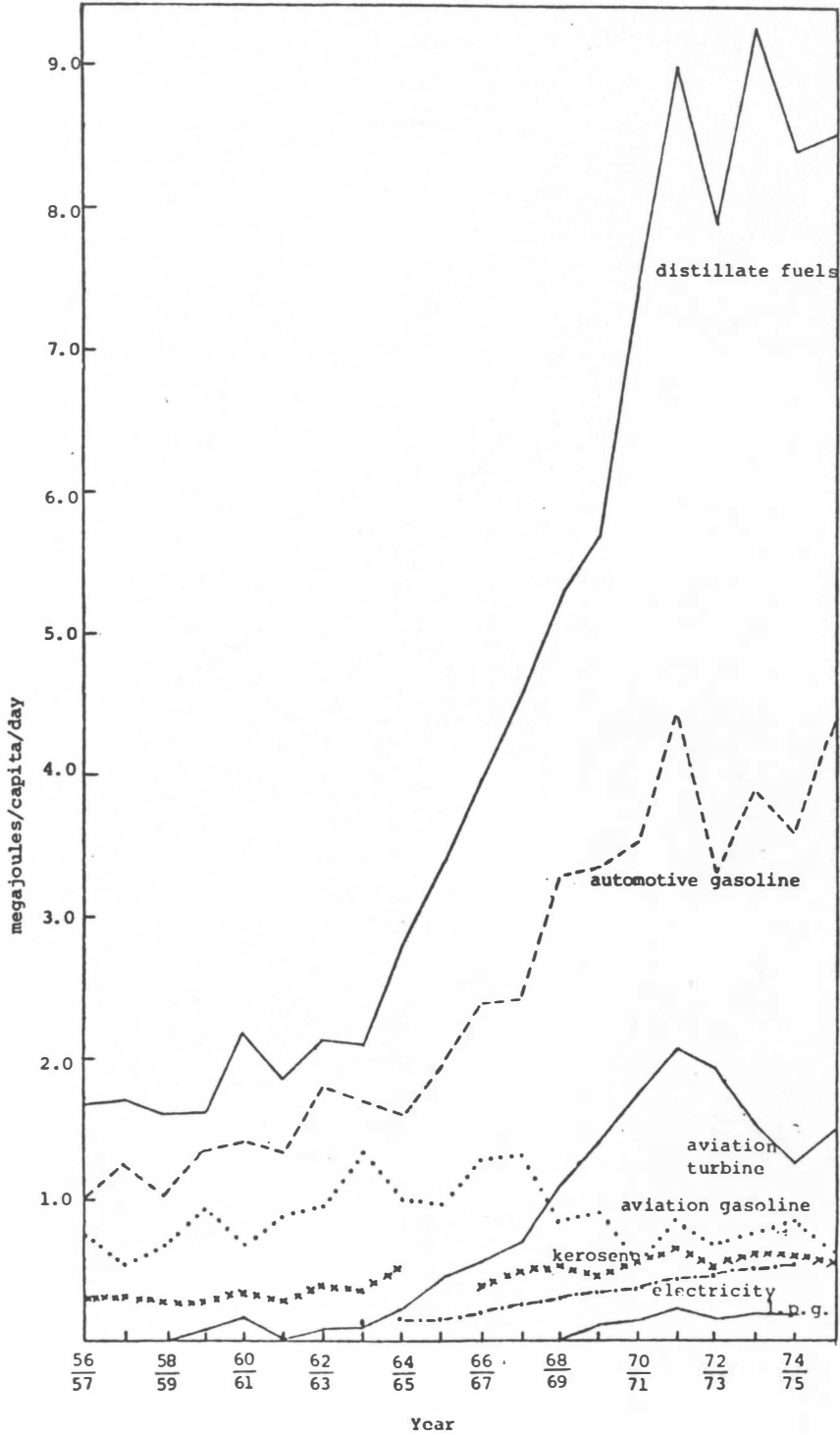




Figure 16 Papua New Guinea Fuel Imports; 1956-1976.



and it is unlikely that this relative end use is significantly different at the national level.

The trends indicated in Figure 16 on the use of motor spirit and distillate closely parallel those in the registration of motor vehicles indicated in Figures 13 and 14. The registration of motor cars drops suddenly from 1972 to 1974, as does motor spirit consumption, although the registration of commercial vehicles, which use predominantly distillate, does not exhibit a decline parallel with the decline for distillate in that period. Despite this latter anomaly there is justification for taking the growth in distillate sales, as well as petrol sales, as indicative of the growth in demand for transport fuels.

The historical growth pattern then, is for the end use of transport fuels to increase at an annual rate of 8% on a per capita basis, or more than double the rate of non-transport energy forms excluding electricity.

#### Determining the nature of traffic in the Lae urban area

It is not uncommon for town planning consultants or traffic engineers to install remote control traffic counting devices along major roadways and, on the basis of data collected, to suggest further expansion of the road network. Indeed, where foot traffic or bicycle traffic is negligible, as in the suburbs of cities in industrially developed countries, this technique may be appropriate, although recent surveys in Great Britain and New York have discovered that foot traffic has been greatly underestimated. In Great Britain, 41% of all trips are on foot, representing two-thirds of all those trips which are less than 4.8 kms (Rigby, 1977). In developing countries, it is usual for large numbers of people to travel on foot, or by a great variety of muscle-powered transport forms like, for example, bicycles and rickshaws.

Previous transport analyses in Lae, conducted either by private consultants (Taylor and Associates, 1971) or by the National Department of Transport, have explicitly viewed transportation as primarily motorised vehicular transport by virtue of only monitoring this sector of local traffic and reporting on economic and engineering

requirements to further facilitate the development of motorised transportation.

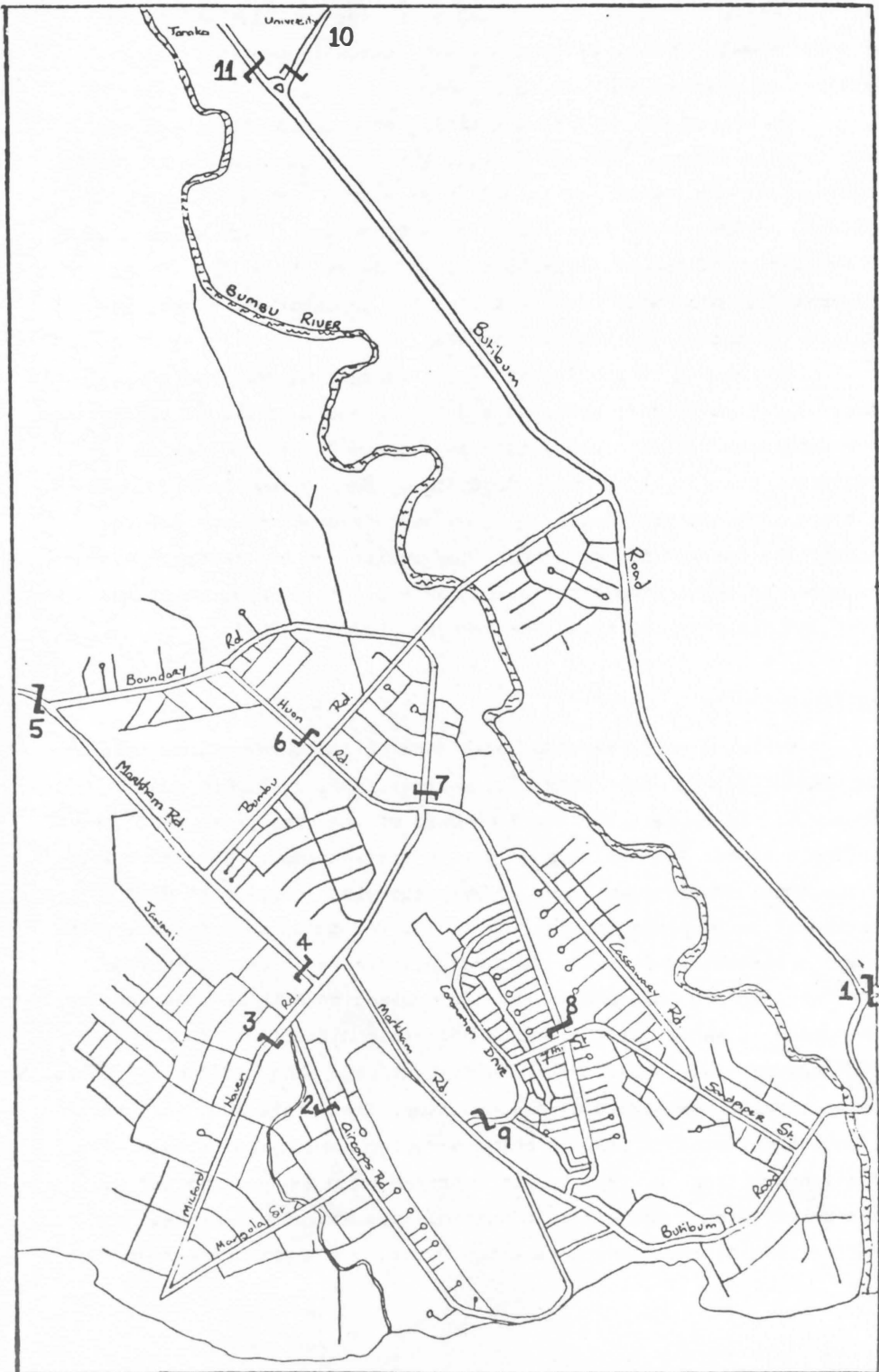
In this study we were concerned to evaluate the means of transport available to the needy as an important component of the total transport network and hence people were employed as traffic observers to enable us to capture data on foot traffic and on the occupancy rates of each transport form. In fact, personal observation of traffic provides a great deal more information than the mere detection of passengers and pedestrians. Traffic is the outcome of social activity, and the minutiae of its dynamic form are a reflection of what is actually happening in the community and of the daily rhythm of these activities. Systematic personal observation of traffic is a much ignored source of rich information about the human ecology of any urban population.

#### The Survey design

Two kinds of transport networks were monitored; the 'formal' transport network of publicly serviced roads and pedestrian footpaths, (Fig.17), and the 'informal' network of footpaths which has evolved in response to the quest for the most convenient access to markets, working places and so on, to and from the place of residence (Fig.25).

For the formal transport network, eleven checkpoints were chosen which represented important entry points to the Lae central business district and industrial area from the settlements and major highways. These checkpoints are shown in Figure 17. Each checkpoint was occupied by an observer between 6.30 a.m. and 6.30 p.m. each day, these hours being determined by the hours of darkness. Vehicles were categorised as private car, taxi, bus, public motor vehicle, heavy truck, light truck (less than 3 tonnes), utility, motor bicycle and bicycle. People on foot were counted as either with, or without, goods. Goods are regarded here as commodities other than small personal effects. The number of people moving by each transport mode was recorded with the greatest accuracy possible. Each checkpoint was monitored on two non-consecutive days; one early in the week and one late in the week, in order to detect and average out the effects of greater market, or other activity, towards the end of the working

Figure 17 The Transportation Survey: Road Checkpoints



week. An hours off-peak monitoring of selected checkpoints was carried out on the weekend, especially Sunday, to allow an estimation of total weekly flow to be made and any change in transportation patterns on non-working days to be noted.

On one of the days of monitoring at each position, for one hour on-peak and one hour off-peak, a representative sample of people walking past the checkpoint in either direction was interviewed. In all, 172 persons were interviewed. Questions were asked which allowed an evaluation of the trip, its origin and destination, and whether informal footpaths were used at any point. Whether the person was employed or unemployed was also asked.

At the end of the survey of the formal transport network, informal footpaths were surveyed and mapped and a series of checkpoints were determined which would enable an assessment of the flow of pedestrian traffic along these footpaths. Monitoring then proceeded on a one to two hourly basis, both on and off-peak, on one day for each of the checkpoints selected. The quality of the footpath system was noted in terms of obstacles and hazards such as mud, water and steep and slippery inclines (Newcombe and Bowman, 1978).

### Traffic patterns

Tables 21 and 22 provide basic data on the observations made at the eleven 'formal' checkpoints of vehicle type, frequency and occupancy. In Table 4 the total numbers of vehicles passing all the checkpoints over the twelve hour period are recorded. The proportion of the total observations made up by particular vehicles at each checkpoint is displayed across the Table, for instance, of cars, 4.4% of all observations in this standard period were at Butibum Bridge, 13.6% at Aircorps Road and so on. In presenting data in this way the assumption is made that there are negligible differences in the frequency of traffic between the different recording periods, as only one checkpoint was manned at any one time. These data show distinctly different patterns of traffic between checkpoints. For example, 39% of all heavy truck traffic is concentrated on roads passing the two checkpoints around the major industrial area whilst the private car traffic is heaviest along Coronation Drive, the major trunk route to

TABLE 21 PERCENTAGE OF THE TOTAL NUMBER OF VEHICLES RECORDED IN THE TRAFFIC SURVEY AT EACH COUNTERPOINT

Counter Position		1	2	3	4	5	6	7	8	9	10	11	Total
		Butibum Bridge	Aircorps Road	Milford/ Aircorps	Markham	Markham/ Boundary	Huon/ Bumbu Rd.	Milford/ Huon	Huon/ 7th St.	Corona- tion	Univer- sity	Taraka	
Vehicle Type	Total (12 hours)	Percentage at each Counterposition											Total
Car	16371	4.4	13.6	15.9	4.6	4.3	9.0	8.4	12.5	21.3	5.1	0.9	100
Bus	586	16.4	18.6	3.0	12.6	12.6	10.8	5.0	4.3	20.7	3.5	2.6	100
PMV	6434	9.5	25.0	4.0	8.8	8.8	6.2	3.8	6.2	11.4	6.0	4.5	100
L. Truck	9743	7.3	15.5	13.9	5.4	5.4	8.0	9.3	8.8	15.0	5.5	2.7	100
Utility	7354	6.2	17.4	16.8	4.4	4.4	7.0	8.5	8.1	17.3	4.2	3.1	100
H. Truck	3336	12.3	21.4	17.4	5.9	5.9	7.2	8.6	4.9	3.5	6.2	3.9	100
Taxi	2023	7.5	21.7	9.2	4.6	4.6	9.4	5.8	6.8	17.4	6.5	2.3	100
M. Cycle	786	13.0	17.1	11.4	3.2	3.2	6.6	8.5	7.2	18.2	5.6	1.1	100
Push Bike	445	12.6	14.8	11.5	8.3	11.3	11.5	8.6	6.9	8.5	1.8	3.9	100
Total	47078	7.0	17.1	13.6	5.5	7.5	8.5	8.4	8.4	16.5	5.1	2.4	100

TABLE 22 TRAFFIC SURVEY MODAL SPLIT BASED ON TOTAL PEOPLE FLOW

Counter Position	1 Butibum Bridge	2 Aircorps Road	3 Milford/ Aircorps	4 Markham	5 Markham/ Boundary	6 Huon/ Bumbu Rd.	7 Milford/ Huon	8 Huon/ 7th St.	9 Coronation	10 University	11 Taraka
12 hour vol (people)	15686	36000	16166	12980	19170	15901	9968	13602	20554	9856	5823
Flow peak hr.	1994	3621	1796	1545	2294	2629	1230	1386	1975	1485	1263
Time begin	16.30	11.30	16.30	16.30	16.30	16.30	16.30	16.30	15.30	16.30	16.30
Offpeak flow	860	1798	889	762	1419	947	562	795	759	589	298
Time begin	13.30	06.30	17.30	13.30	13.30	09.30	08.30	17.30	17.30	09.30	10.30
Modal split (%)											
<u>A/Peak</u>											
Car	11.0	12.2	24.6	14.8	10.5	19.5	26.3	28.1	27.2	16.0	6.9
Bus	6.0	7.9	0.0	12.4	2.3	7.3	6.8	1.1	9.0	4.9	7.1
PMV	26.6	43.2	12.9	34.8	35.0	16.1	13.4	30.4	28.0	41.9	42.1
L. Truck	15.8	9.9	20.8	14.3	19.3	18.5	23.3	19.7	12.9	14.6	26.6
Utility	8.9	6.7	14.3	5.1	8.9	12.0	10.3	7.7	13.4	7.2	7.0
H. Truck	6.3	4.4	7.1	5.4	11.1	5.2	6.7	6.2	1.4	10.2	3.6
Taxi	2.7	3.2	1.1	1.8	2.9	3.7	4.1	1.7	2.9	3.7	2.5
Motor cycle	0.5	0.6	0.5	0.3	0.6	0.4	0.6	1.0	0.8	0.4	0.2
Push bike	0.3	0.2	0.4	0.2	0.3	0.2	0.6	0.2	0.2	0.1	0.2
Pedestrians	14.7	7.9	12.4	6.9	5.4	8.6	6.3	3.0	2.7	0.8	2.9
Pedestrians with goods	7.2	3.8	5.8	3.8	3.7	8.5	1.6	0.9	1.5	0.2	0.9
Total	100	100	100	100	100	100	100	100	100	100	100
<u>B/Offpeak</u>											
Car	19.3	5.5	22.4	10.8	8.6	15.9	23.2	34.7	27.7	22.3	5.8
Bus	3.7	3.8	0.0	13.1	0.5	8.7	2.4	3.4	17.7	4.6	3.8
PMV	22.4	39.7	12.4	41.7	46.5	20.8	12.6	26.4	28.5	36.6	53.9
L. Truck	9.8	19.9	8.7	9.3	18.3	14.9	19.4	12.4	9.6	19.9	12.5
Utility	13.3	6.0	7.3	5.7	10.1	8.1	18.0	7.4	3.7	8.1	11.2
H. Truck	9.1	6.1	4.7	6.0	5.0	4.9	8.6	5.0	1.6	5.6	4.4
Taxi	2.4	2.0	5.0	3.5	2.3	3.6	4.5	3.3	5.4	1.7	2.3
Motor cycle	0.3	0.2	1.3	0.2	0.3	0.2	0.9	1.3	0.9	0.7	0.0
Push bike	0.6	0.2	1.0	0.2	0.3	0.3	0.2	0.2	0.5	0.0	0.7
Pedestrians	11.9	14.3	26.0	7.3	5.9	20.4	8.7	4.9	2.8	0.3	4.7
Pedestrians with goods	7.2	2.3	11.2	2.2	2.2	2.2	1.5	1.0	1.6	0.2	0.7
Total	100	100	100	100	100	100	100	100	100	100	100

the central business district. Although overall numbers are small, bicycle traffic is evenly distributed among all inner city locations, and only comparatively less at the checkpoints that are six or seven miles out of town (i.e. Taraka and University).

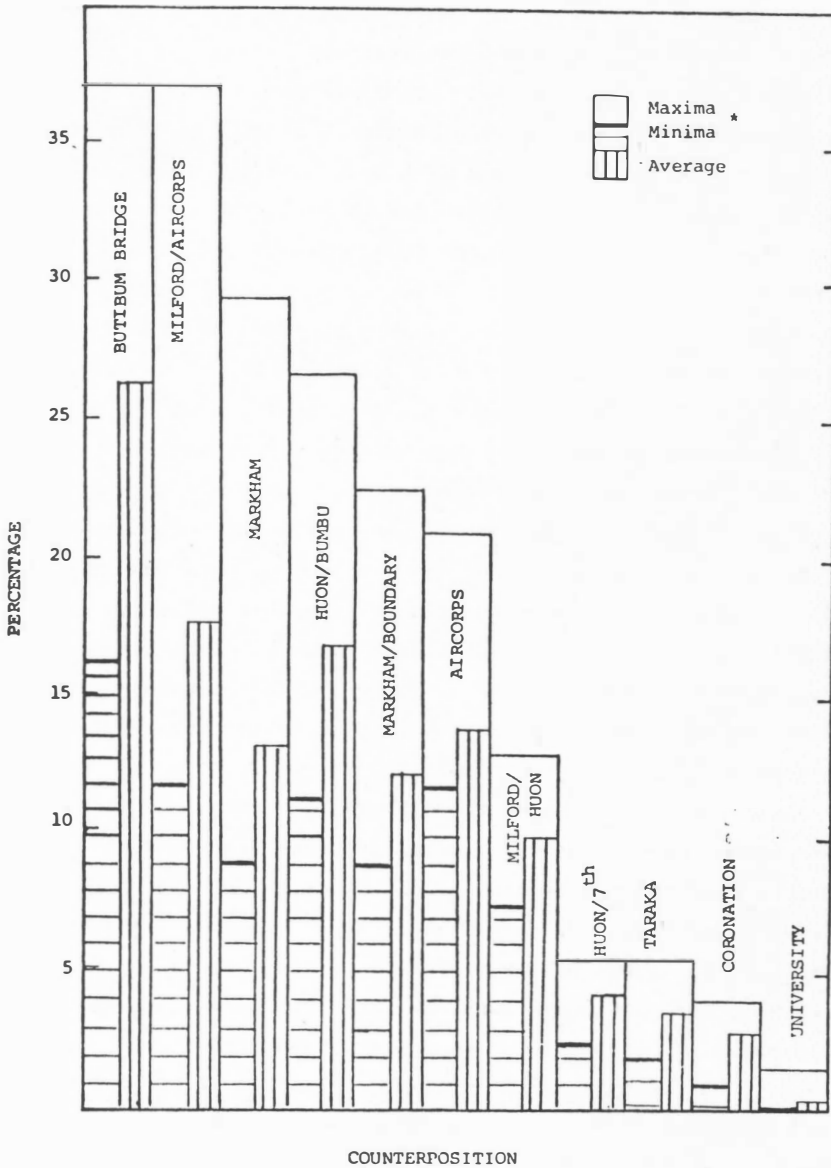
Table 22 shows the total flow of people past each checkpoint. Firstly, the number of people moving past each checkpoint in a twelve hour period is provided. The range of people traffic volumes is from 5823 for the Taraka Settlement checkpoint which is one of the two distant checkpoints, up to 36,000 for the checkpoint at Aircorps Road next to the main produce market. Of course, in no case can the total movements recorded at different checkpoints be added to give a meaningful picture of total vehicles on the road, or people on the move.

Secondly, Table 22 presents a detailed analysis of the number of people travelling by each transport mode as a percentage of total people traffic for the hours representing the peak and trough of traffic at each place. The data presented in this section of Table 22 are those used to construct Figure 18 the graph of on-peak and off-peak pedestrian traffic as a proportion of total people traffic for each checkpoint. The proportions of vehicles of each kind and the people traffic at each checkpoint is basic information for planning further development for either road systems or facilities for pedestrian and bicycle traffic.

All of these data are summarised in Table 23 which indicates the proportion each vehicle type contributes to total traffic; the importance of each vehicle type as a mode of passenger transport; and the average occupancy of each vehicle type. From data presented in Tables 23 and 20 it can be calculated that private cars use 28% of the energy used for passenger transport, and that they represent 35% of total traffic and carry 16% of people recorded moving past the checkpoints. The average occupancy of major vehicle types is 1.8 for cars, 15.7 for buses, 8.5 for public motor vehicles (PMVs), 2.5 for taxis and 2.9 for light trucks. The average occupancy for PMVs is very low compared to an estimated average capacity of 25-30. Since PMV traffic is 14% of the total and PMVs carry 30% of all people travelling in vehicles, there is a considerable capacity for the efficiency of their operation to be enhanced and better use of the same transport infrastructure and transport energy to be made.



Figure 18 Pedestrian Traffic as a Percentage of Total Passenger and Pedestrian Traffic.



\* These are maxima and minima values for foot traffic as a percentage of total people traffic at each location. The values have been averaged for the two days of recording. They are not in direct correspondence with the data of Table 5 where modal splits are shown for the particular hours at each location when the flow of people was at its maximum and minimum.

TABLE 23 AVERAGE FLOW OF TRAFFIC AT A FIXED LOCATION IN LAE BETWEEN 6.30AM and 6.30PM

Vehicle type	Average* frequency of vehicles - 12 hours		% of total vehicles	Average occupancy		Average numbers of passengers & pedestrians passing the hypothetical average checkpoint	Averaged people modal split at checkpoints (%)	People modal split including informal foot- path system (%)
Car	1489	31	34.8	1.8	0.3	2680	16.2	15.3
Bus	52	7	1.2	15.7	4.6	816	4.9	4.7
PMV	586	22	13.7	8.5	2.9	4981	30.1	28.5
L. Truck	886	26	20.7	2.9	1.1	2569	15.5	14.7
Utility	668	24	15.6	2.4	0.8	1603	9.8	9.2
H. Truck	304	17	7.1	3.0	1.2	912	5.5	5.2
Taxi	184	13	4.3	2.5	0.3	791	4.8	4.5
Motor cycle	73	8	1.7	1.2	0.2	124	0.7	0.7
Push Bike	38	6	0.9	1	0.0	38	0.2	0.2
Sub-totals	4280	154	100.0			14514		
Pedestrians						2036	12.3	11.6
Informal Foot- path pedestrians						936		5.4**
Total						17486	100	100

\*Weighted average of all checkpoints in proportion to their recorded traffic volumes.

\*\*This determination was based on a survey made of the informal footpath networks in Lae. The resulting value is a minimum one, however, as not all of such footpaths were monitored, and no recordings were made of transportation within settlements where most movement is on foot.

TABLE 23- ATTACHMENT

FOOTNOTES

Informal footpaths (for locations A-M see Figure 14)

Road system counterpositions inadequately cope with walkers on informal footpaths at:

A + B - people moving to and from between Botanical Gardens and C.B.D.

L - people moving between C.B.D. and Sandpiper Street area

M - people coming across Bumbu Bridge

J, K + E - Butibum Road - C.B.D.

Butibum Road - Markham Road

Butibum Road - Market area

To determine numbers using these positions I have looked at on-peak and off-peak values for each position. If the same, then they have been multiplied by 12, if different then I have assumed 3 hours peak time/day and 9 hours off-peak time. Thus:

$$A \quad 65 \times 12 = 780$$

$$B \quad 3 \times 110 + 9 \times 56 = 834$$

$$L \quad 169 \times 12 = 2028$$

$$M \quad 338 \times 3 + 9 \times 129 = 2175$$

$$J \quad 60 \times 12 = 720$$

$$K \quad 128 \times 3 + 77 \times 9 = 1077$$

$$G \quad 100 \times 3 + 50 \times 9 = 550$$

$$\begin{aligned} \text{Total pedestrians at all checkpoints} &= 43371 \text{ ) - 2 days} \\ &\quad \text{) 12.3\%} \end{aligned}$$

$$\text{Total people traffic} \quad \quad \quad = 351182 \text{ ) - 2 days}$$

$$\begin{aligned} \text{New pedestrians (8164) x 2 to give two day flow + counterposition pedestrians (43371)} &= 59699 \\ &= 17.0\% \text{ total people} \\ &\quad \text{traffic} \end{aligned}$$

Pedestrian traffic is compared with the total people traffic recorded at the checkpoints in the right-hand column of Table 23. Here it can be seen that the lowest estimate of pedestrian traffic, as a proportion of total pedestrian and passenger traffic, is 17%, but not all of the informal footpaths in Lae have been monitored in this survey, a final figure for pedestrian traffic of 20% of total people traffic is considered to be a reasonable estimate.

In Figure 18, for each checkpoint, a maximum and minimum percentage of total persons passing as pedestrians is presented, as well as an hypothetical average percentage for any one hour. Those checkpoints where the pedestrian traffic, at certain hours, exceeds 20% of the total flow of people, represent major exit routes from populous settlement areas close to town, or, in the case of the Milford/Haven Aircorps Road and Aircorps Road checkpoints, the major workplace and marketplace respectively. The two lowest levels of pedestrian traffic were experienced at points about 9kms from town where it is obvious that walking is the least attractive transport option, if the object is to travel to facilities in town.

The fluctuations in passenger and pedestrian traffic in relation to one another over the recording period are given in Figures 19 to 24 for six selected checkpoints where walking is a prominent transport mode. It is significant that in all cases presented pedestrian traffic exceeds, or is of the same order as, passenger volumes in private cars. Distinct patterns emerge for the twelve hour period. The greatest passenger loads for light trucks and utilities are for the 6.30-7.30 a.m. period and after the end of the working day, from 4.00-4.30 p.m. From observation it is clear that during these periods commercially or industrially-owned vehicles are carrying their employees to and from the workplace. In the industrial area (Figure 11) the number of passengers carried by this mode exceeds all others right throughout the day and in all situations it exceeds or is close to the most important passenger vehicle mode for the morning period prior to the beginning of the working day, that is, between 6.30 a.m. and 7.30 a.m.

A fairly consistent diurnal pattern of weekday traffic exists for other passenger vehicles and pedestrian traffic. Generally, there are peaks centred on 7.30 a.m. and 4.30 p.m. with a smaller peak at about midday. This pattern is varied significantly only for the central

Figure 19 Diurnal Traffic Flow: Butibum Bridge

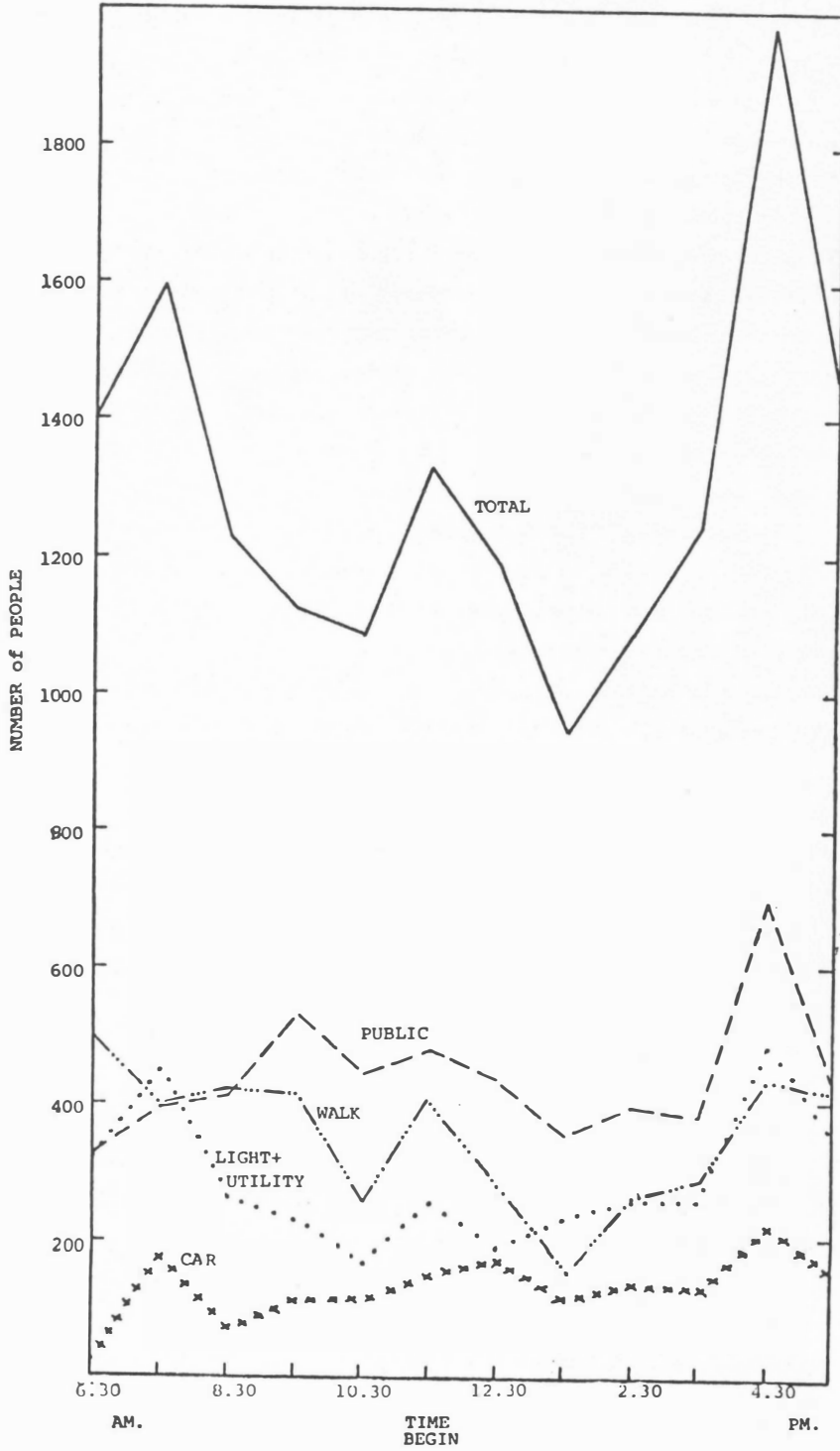


Figure 20 Diurnal Traffic Flow: Aircorps Rd.

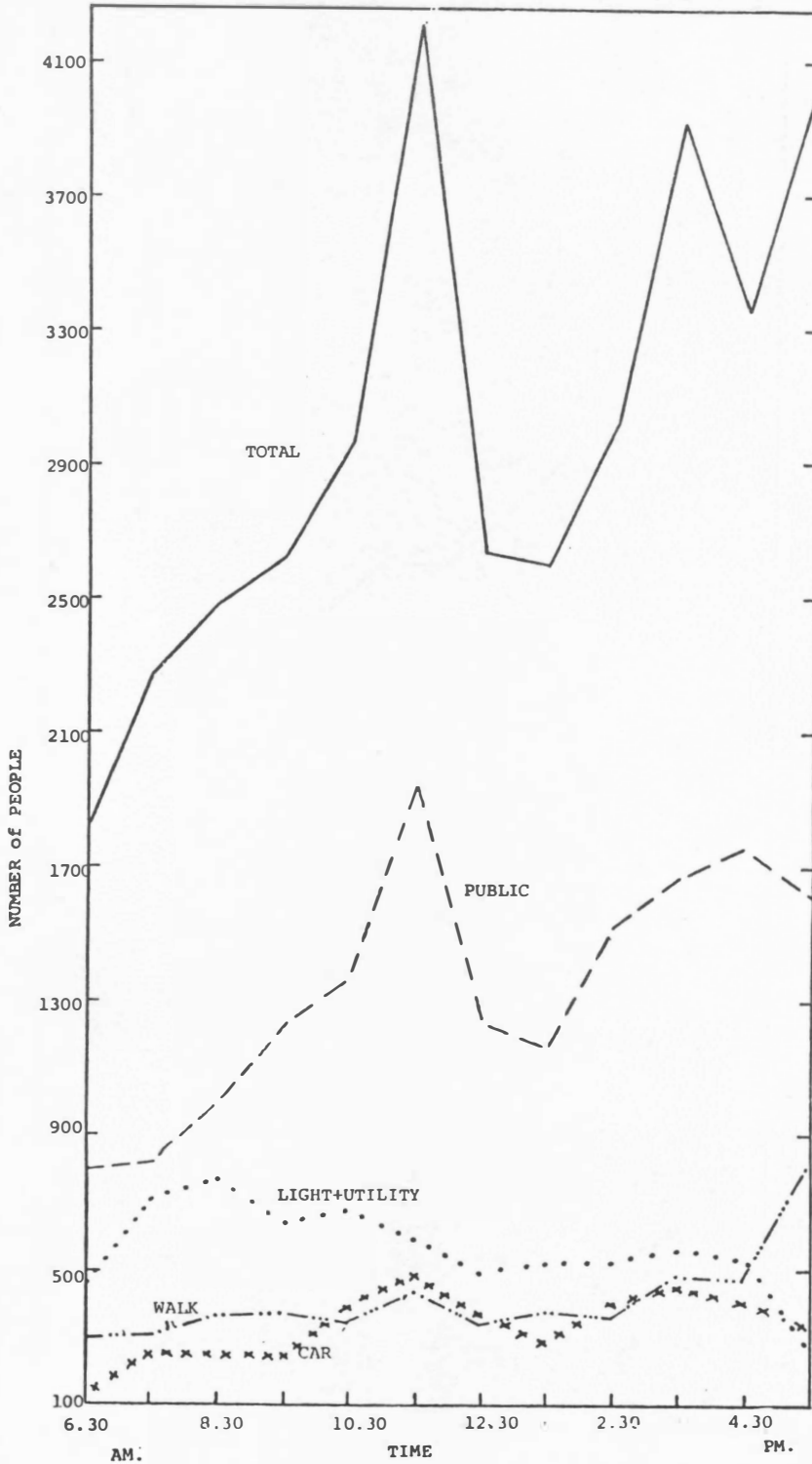


Figure 21 Diurnal Traffic Flow: Markham Rd./Boundary Rd.

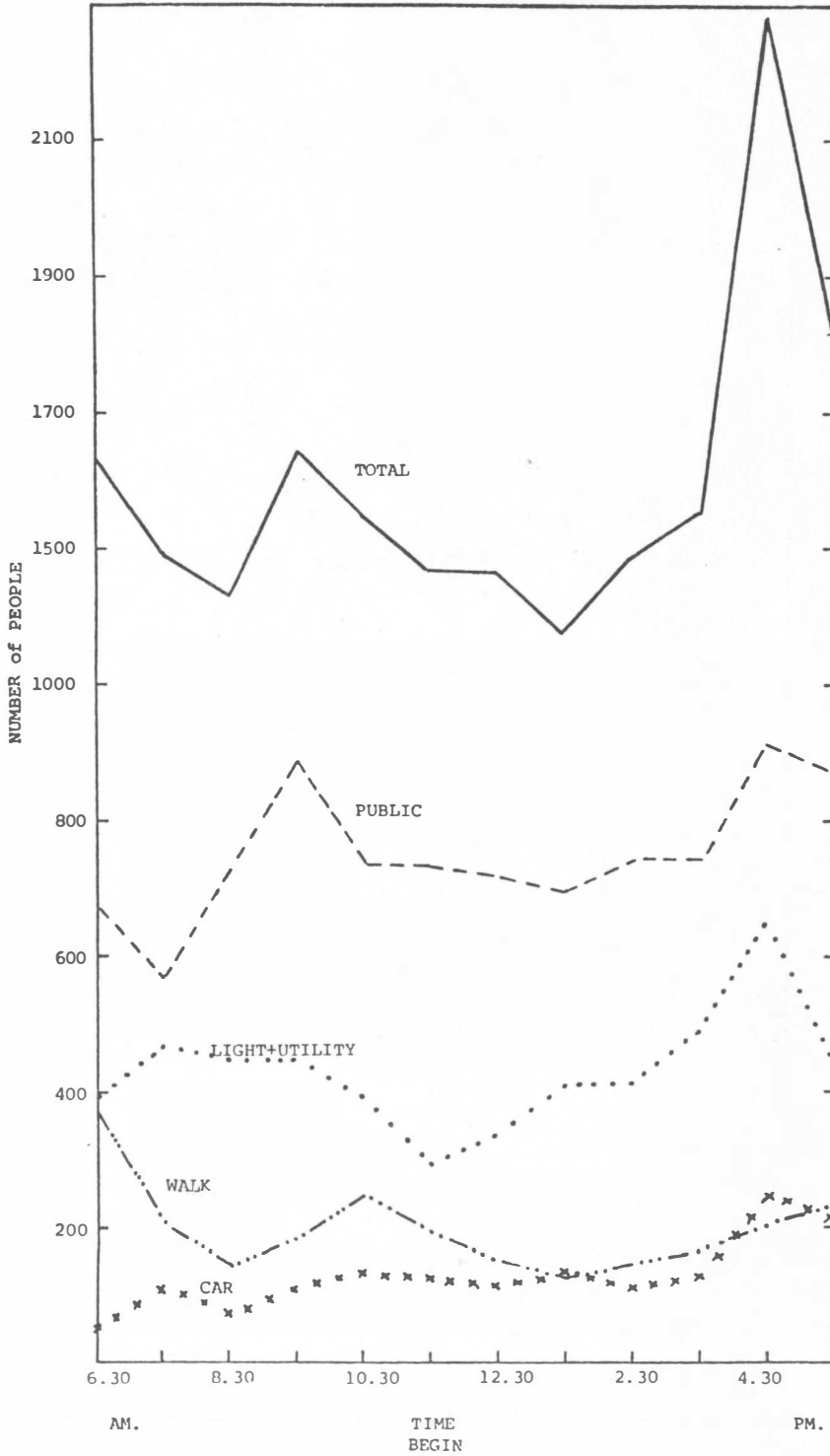


Figure 22 Diurnal Traffic Flow: Milford Haven Rd./Aircorps Rd.

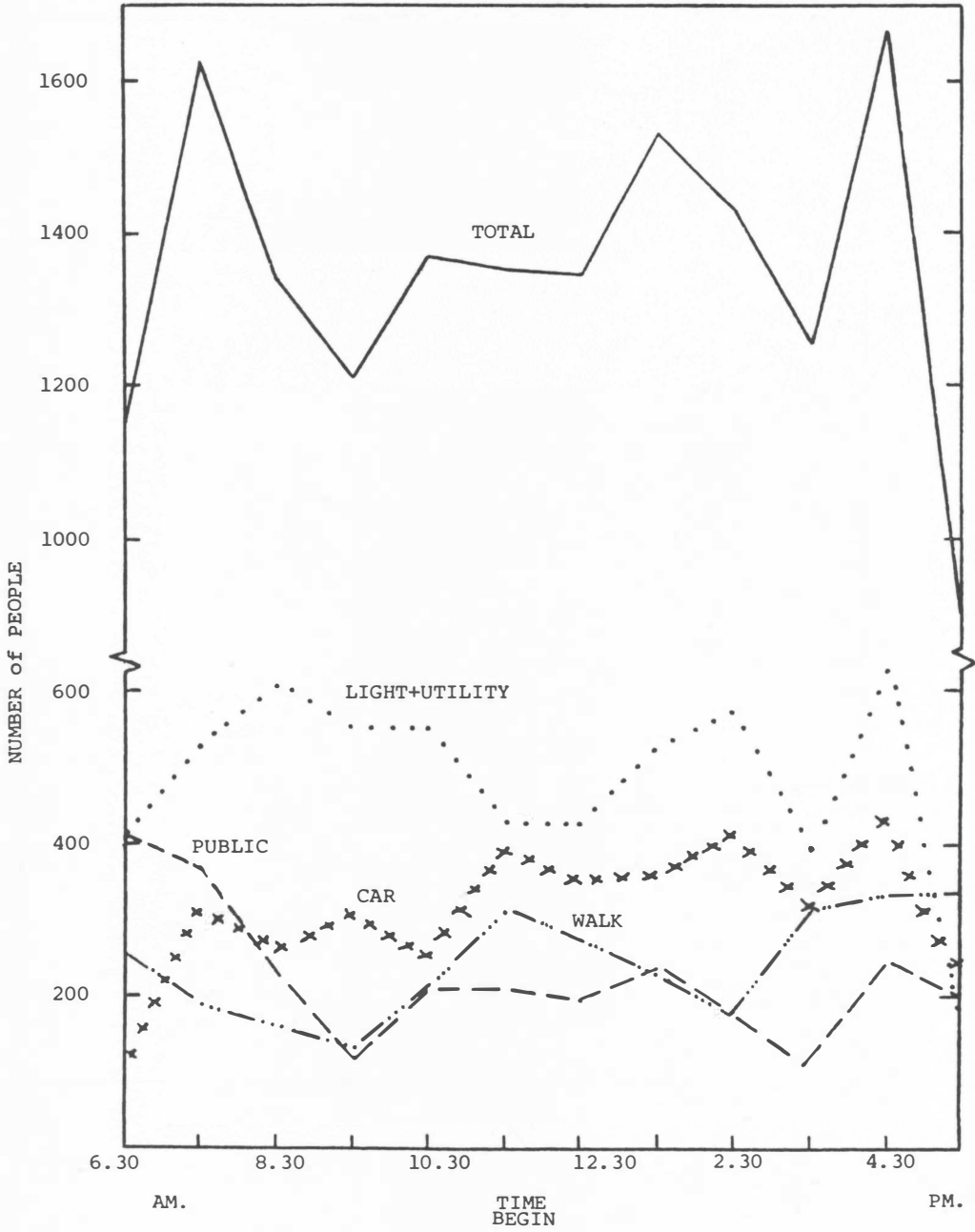




Figure 23 Diurnal Traffic Flow: Milford Haven Rd./Huon Rd.

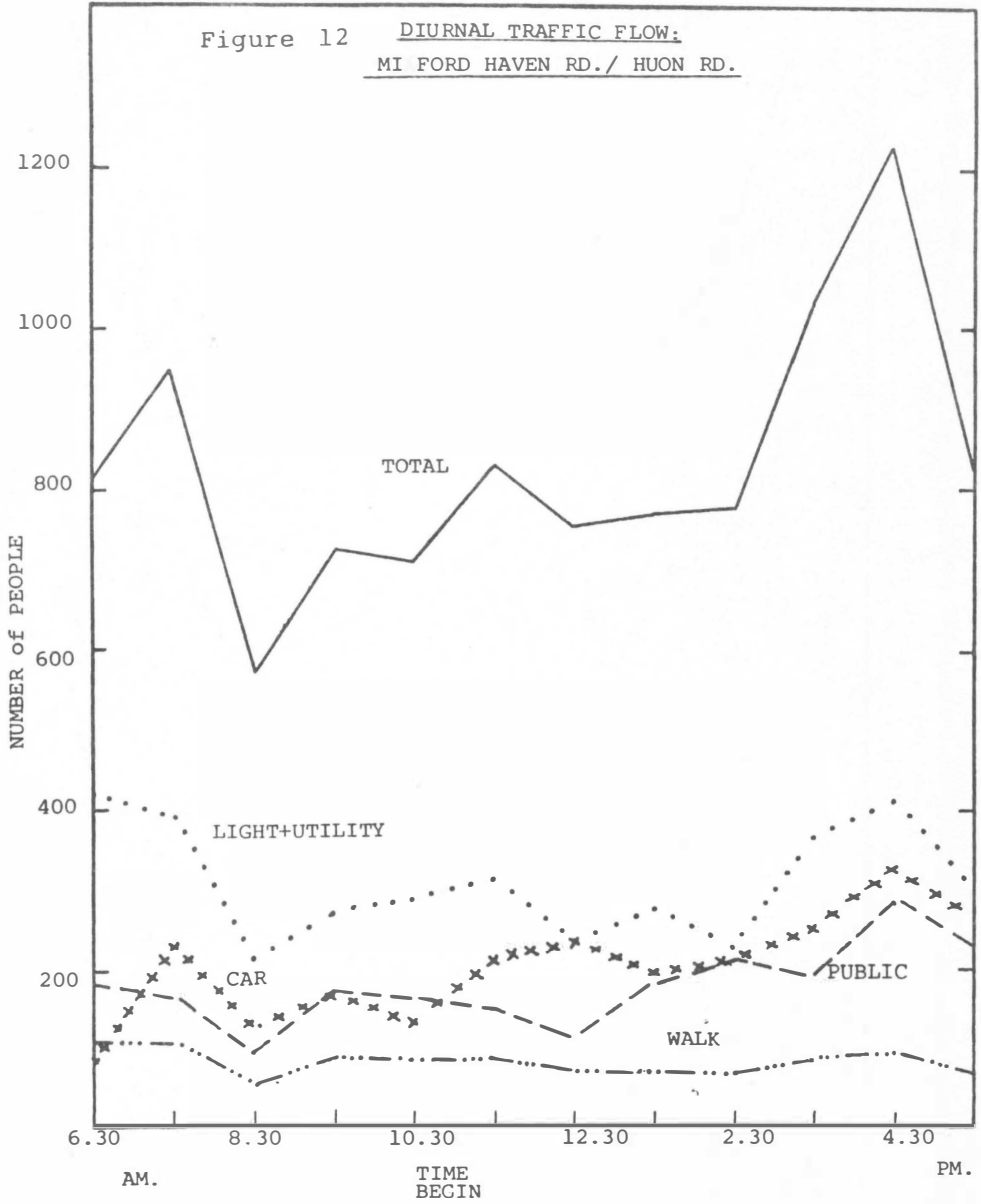
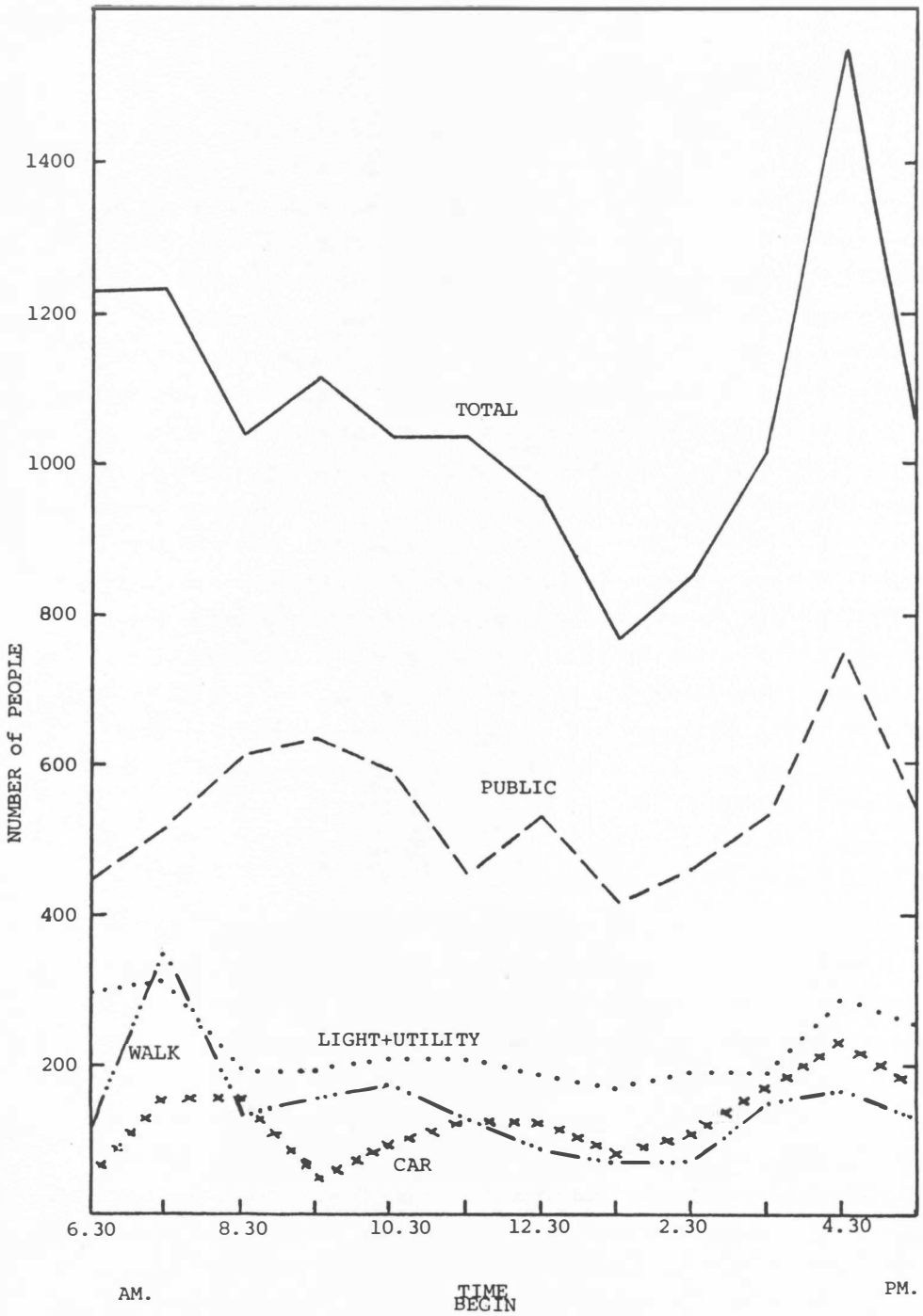


Figure 24 Diurnal Traffic Flow: Markham Rd.



market area where passenger volumes for private cars, public transport and pedestrian traffic peak around 11.30 a.m.

#### Pedestrian traffic along informal footpaths

We have documented substantial pedestrian traffic along major roadways; along either well or poorly defined footpaths or merely along the unprepared verge of these roads. While the magnitude of this pedestrian traffic should stimulate decision-making in favour of augmenting pedestrian safety and movement, there is a further considerable volume of pedestrian traffic away from the major vehicular transport routes. That part of the network which is outside the settlements and which connects low income settlement areas with workplaces, markets and key institutional areas and recreation zones is shown in Figure 25. The number of people using these footpaths at the checkpoints A to M is given in Table 24. It is difficult to accurately predict the level of double counting of people who used both the footpaths along roadways where there were checkpoints and the informal footpaths which were monitored. However, in our estimation, between 5% and 8% of the combined total of pedestrian and passenger traffic is carried by informal pedestrian ways. This makes foot traffic in Lae, outside of the settlement areas, to be in direct competition with vehicular traffic, at perhaps 20% of total combined pedestrian and passenger traffic.

#### Somatic energy use in transport

Somatic, or muscle energy, derived from food eaten, is put to work by people for transportation either by walking or pedalling bicycles. In Lae, bicycles carry less than 0.2% of total pedestrian and passenger traffic and road conditions do not encourage their use. Even so, local sales of bicycles are increasingly steadily, according to local dealers, and are now at the level of six to eight per week. Nevertheless, walking is the main outlet of somatic energy use for personal mobility and in this report we have demonstrated its importance relative to vehicular transport. But the data presented so far have not indicated the distances people walk and therefore the total somatic energy use in the journey to work, to market and so on remains unclear.

Figure 25 Lae Transportation Survey: Footpath Network

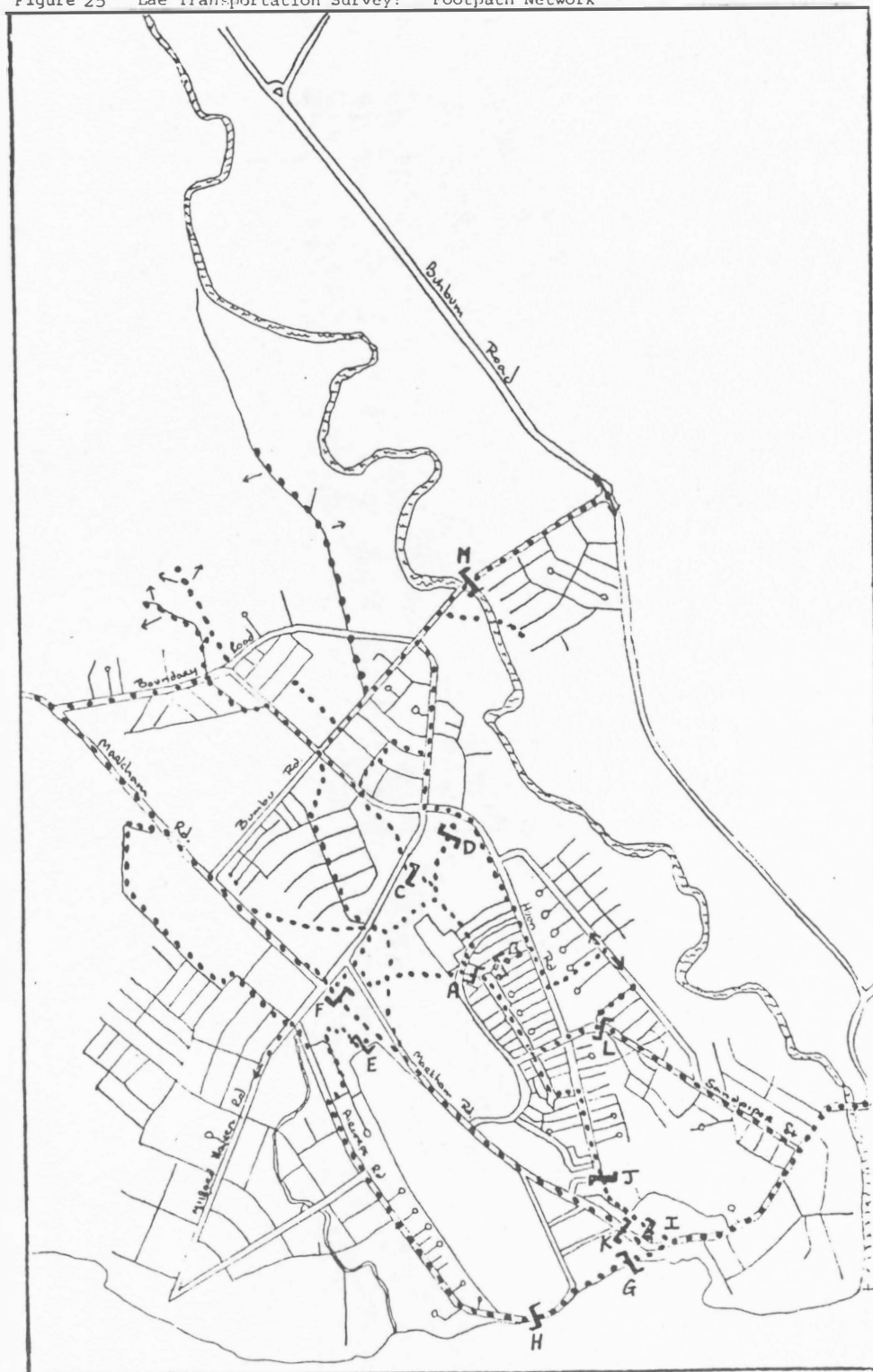


TABLE 24 TRAFFIC VOLUMES OF INFORMAL FOOTPATHS

COUNTERPOSITION	PEAK HOURLY RATE	OFF PEAK HOURLY RATE
A. Central Avenue/Botanic Gardens	67	60
B. Central Avenue/Huon Road	110	56
C. Botanic Gardens/Erica	101	58
D. Botanic Gardens/Huon Road	80	51
E. Markham Road/Aircorps Road	205	130
F. Markham Road/Milford Haven Road	94	77
G. Markham Road/Esplanade	100	51
H. Esplanade	80	70
I. Butibum Road/C.B.D.	34	28
J. Huon Road/Markham Road	65	55
K. Markham Road	128	77
L. Seventh Street/Sandpiper Street	*	169
M. Bumbu Bridge	338	129

\* No count made.



Plate 2: Informal footpath, Lae, 1977

In order to gather this information, a sample of pedestrians passing each checkpoint was interviewed to ascertain distance travelled or intended to be travelled. Table 25 provides this information and from these data and those used to construct Figure 18 we can estimate the average distance travelled per person per trip as 1.43km. By multiplying this figure by the recorded pedestrian population we get the total kilometres walked (excepting small double-counting)<sup>1</sup>. The somatic energy costs of this travel, which is roughly 0.23 megajoules/kilometre, is  $72 \times 10^5$  MJ for the year. This can be compared to the extrasomatic energy for petroleum fuels used for road transport in Lae of  $7314 \times 10^5$  MJ, excluding earth moving of  $761 \times 10^5$  MJ for 1976-1977. In fact, from data gathered from the Department of Transport in Lae (G. Beaver, pers. comm., Department of Transport, 1977) on the destination of vehicles by vehicle type along the Markham Highway we have estimated that  $3200 \times 10^5$  MJ are used in travel to the Markham Valley, Wau-Bulolo, Nadzab Airport and the Highlands (see Appendix 1). This reduces road transport energy use in the Lae urban area to  $4114 \times 10^5$  MJ for the reference year, and of this reduced amount the muscle energy used in transporting the 20% of the population who move on foot is 2.0%.

Table 25 contains additional information enabling the construction of a profile of the average pedestrian. Generally, 59% were employed, 13% were students and 28% were unemployed. Of those interviewed 93% either preferred to walk, or presumably find it too expensive to travel by other means; the remaining 7% mostly use vehicular transport to move around. With regard to the future development of the transport in Lae it is of great interest to note that two-thirds of the respondents take shortcuts, or as defined in this report, take informal footpaths (see Plate 2).

#### Scenarios for the future of personal transportation

One of the difficult areas of the development debate is that which questions the nature and content of an improvement in the quality of life, and by implication, the composition of human well-being. Even

<sup>1</sup>Table 8 indicates that 95% of the pedestrians were to make the return trip. So the figure of 2.86kms is used in this calculation. For the average day, 21,685 people passed by all checkpoints on foot. By including pedestrians using informal footpaths this figure becomes about 29,850.

TABLE 25 RESPONSES BY PEDESTRIANS TO INTERVIEW QUESTIONS

	No. of respondents	Ave.distance for trips being made (Km)	No.making return trip	No. employed	No. students	No. unemployed	No. who mainly walk	No.who mainly use vehicles	No.who mainly walk on roads	No.who take shortcuts
Butibum Bridge	23	2.3	23	13	1	9	23	-	8	15
Aircorps Rd.	25	3.1	24	14	2	9	24	1	9	16
Milford/Aircorps	23	3.8	22	15	6	2	20	3	7	16
Markham*	-	-	-	-	-	-	-	-	-	-
Markham/Boundary	10**	3.2	10	7	-	3	10	-	5	5
Huon/Bumbu	19	3.5	18	14	4	1	18	1	8	11
Milford/Huon	25	3.1	22	15	7	3	22	3	2	23
Huon/7th St.	19	1.9	10	11	-	8	16	3	6	13
Coronation	20	2.9	18	12	1	7	19	1	8	12
Uni./Taraka	8**	3.9	8	1	-	7	8	-	3	5
Total	172	1.43+	166	102	21	49	160	12	56	116
% of Total	100		96.5	59	13	28	93	7	32.6	67.4

\* No interviewing at this checkpoint

\*\* Only one hour of interviews.

+ This represents the weighted average distance travelled by a pedestrian per one-way trip, because the proportion of pedestrians interviewed to total pedestrian flow at each checkpoint has been considered.



though increasing the quality of life is, as an abstract concept, a universally agreed upon goal for developing countries, the nature of the component parts of which quality of life is alleged to be comprised is a matter of individual perception, and is therefore highly subjective. Nowhere is the controversy surrounding the quality of life issue more clear than in respect of ownership of the private car and its role in economic development in the Third World. In this section, we intend to provide no more than basic information on the implications of possible future trends in private transportation, postulating in each case a movement away from legs or pedestrian traffic, to public motorised transport and then, in turn, to the private car. Figure 26 is the diagrammatic representation of the relative energetic efficiency and current importance of the major public transport modes in terms of moving people around the Lae urban area. Figure 27 is a graphic representation of the increase in per capita energy use which would be experienced if there were a 2.5% and 10% intermodal transfer between pedestrian traffic, public motor vehicles and private motor cars. In effect the calculation here is to ascertain the total per capita energy use for each year, if between now and the year 2000 people moved from walking to using public transport, and away from public transport to private motor cars at the rate of 2.5%, 5% and 10% of the population remaining in each group at the end of each year, starting with the 1977 configuration. This has been done for the Lae population of 1977 and for the known cross-section of the population using each transport mode at that time. Current population growth rates are built into this model which allows for a 3% natural growth in the urban population and an additional 2% due to migration which comes on a 50/50 basis into the pedestrian and public transport user categories. The mathematical basis of the model is appended (see Appendix 3).

Starting with the 1976/1977 figures of petroleum energy resources used to move an individual around Lae by car and by PMV it can be seen, from the range of possibilities presented here, that a shift to private car use, from walking and through travelling on PMVs will increase transport energy requirements, for passenger transport only, from between six and twelvefold by the year 2000, assuming per capita consumption of energy of PMVs and cars remains at 1977 levels.

Fig. 26 Relative Energetic Efficiency and the Current Importance of Major Public Transport Modes in Lae.

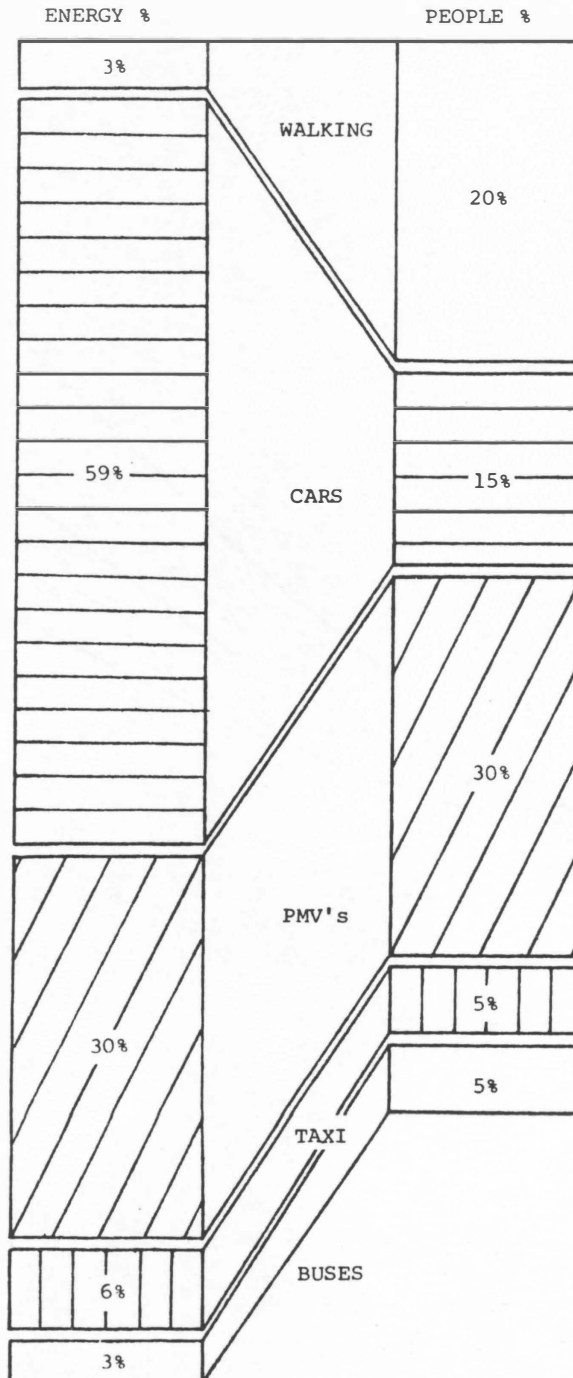
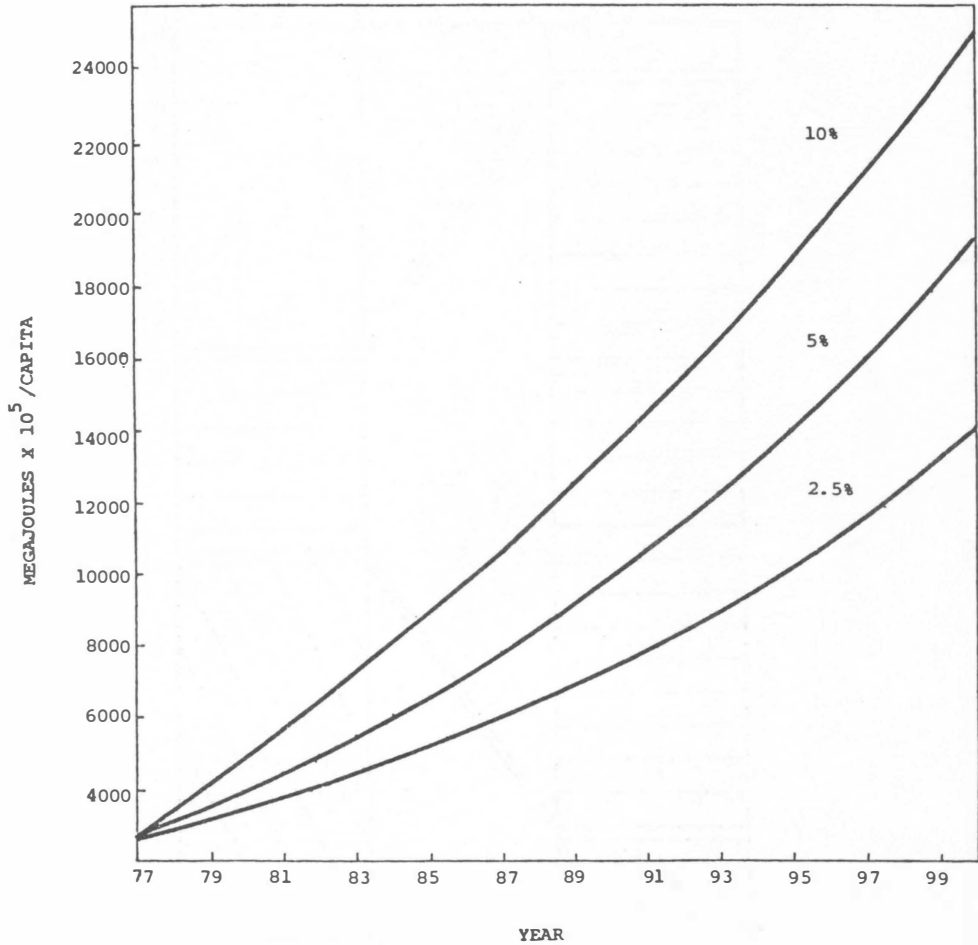


Figure 27

Transport Energy Projections 1977-2000.



### Emerging issues and policies

Transport energy use must be put in perspective within both the Papua New Guinean energy and global energy context. The so-called 'global energy crisis', brought into prominence by the oil embargo of the West by the OPEC nations in 1973/74 is, more than anything else, a crisis in the availability of liquid petroleum-based fuels for transport. While demand for those energy forms is very largely generated by the North American and Western European nations, the inevitable depletion of these resources during the next 15 to 30 years (WAES, 1977) will have potentially severe repercussions for small Third World nations such as Papua New Guinea. Already, within the Papua New Guinea economy, motor spirit and distillate for transportation represent the majority of the total energy demand and even now, real prices of transport fuels at the main ports are greater than in Australia and double U.S. prices. Also, balanced rural development will remain a dream as long as the real price of transport fuels in Papua New Guinea's Highlands and remote islands is up to four times mainport prices. During the seventies the price of petrol in Papua New Guinea rose 1.5 times faster than the consumer price index, reflecting the more general and serious trend facing the non-oil producing Third World. The real price increase of oil for them, as a percentage of their gross national product, was far more serious than for the industrialized countries (see Powelson, 1977).

Within the Lae urban ecosystem transport fuels comprise 55% of total energy use if the necessary function of bunker fuels is regarded as a legitimate part of local energy flow. It is also clear that in the economy as a whole the growth rate in demand for transport fuels is double that for other fuels such as fuel oil, LPG and kerosene, with the exception of electricity. From these facts it is clear that despite the tiny volume of Papua New Guinea's liquid transport fuel requirements in relation to global demand, further growth in the use of these fuels, that is of motor spirit and distillate, at the historical level is likely to make Papua New Guinea and, in consequence, the well-being of its citizens, critically reliant on an increasingly scarce and expensive commodity. This is justification alone for a close analysis of the options which now present themselves, on the basis of this and other research, for reducing future reliance to a level which

does not threaten economic or political security at the national level and does not hamper the capacity of Papua New Guineans to secure their survival requirements and to experience a growth in their perceived quality of life.

The quest must now be for the most socially optimal use of relatively scarce transport fuels and for the forward design of transport systems and technology to achieve desired goals with minimum energy cost. This implies three components of an overall strategy; conservation, sensitive social and urban planning, and the development of alternative, locally-available, renewable energy sources for transportation.

#### Social and urban planning

Illich (1974) and his colleagues (Jean Robert, et al, CIDOC, Mexico) have alerted us to the social implications of a high-speed motorised transport system and the analysis undertaken in this research further illuminates their thesis. Illich claims that any transport system designed to cater for travel in excess of 40 kph is bound to distort expenditure in favour of the motorised elite and make low cost and effective mobility increasingly difficult for the majority. This has been regarded as an esoteric concept in the industrialized West, for even if intelligible to planners, motorised transport systems have extraordinary momentum and change comes reluctantly. But for Papua New Guinea the validity of Illich's concept is much more readily apparent.

In Papua New Guinea two elements of future transportation are already clear; one, universal access to a private car is, regardless of desirability, impossible; and two, since the transport mode of the majority of rural dwellers is walking, it is this form of mobility which is most compatible with the existing pattern of social interaction, and which will continue to dominate in a village society. Muscle energy is not only the cheapest of the renewable energy forms but, because of its universal availability it is one which generates the greatest social equity; an important goal of Papua New Guinea's national development strategy.

### Bicycle technology

The efficiency with which muscle energy is used is almost doubled by translating it into work through bicycle technology, a technology which makes man's muscles as efficient in generating movement as is found for specialised animals such as birds (Tucker, 1975). The additional resource requirements for bicycle traffic are minimal, involving only the energy cost of constructing and maintaining the bicycle through its lifetime and the material requirements of bicycle paths. In the early stages of the development of bicycle networks, dual footpath and bicycle path systems are compatible and do not cause a reduction in safety. There is no question, on the other hand, that the rapid development of a motorised transportation network to the exclusion of low speed muscle-driven systems has resulted in serious increases in mortality/morbidity in the Third World communities.

Pedal power, as it is best known, offers much more than an efficient and cheap transport system. Apart from adapting bikes for hauling cargo, the technology can be adapted to stationary applications, such as water pumps, winnowers, grain grinders, hydraulic pumps and winches (Reddy, 1978). The technology is also adaptive to the development of an industry technology and can be regarded as a step-off point towards the creation of a truly indigenous technological capability. After all, the rise of the Japanese economy is alleged to have been based initially on the evolution of a Japanese bicycle spare parts industry leading on to the local production of bicycles (Jacobs, 1972). A previous government committee of inquiry into transportation in Papua New Guinea recognised the value of bicycle technology to national development and to effective low cost transportation (Commission of Inquiry into Standardisation of Selected Imports, 1975), and, earlier than this, town planning consultants (Taylor and Associates, 1971) recommended bicycle paths for Lae. Both of these reports have had demonstrably little effect on facilitating bicycle transportation as a socially accepted transport mode.

There is a great need to plan town and rural areas around the use of bicycles and to deliberately cater for pedestrian traffic as opposed to development that is exclusively orientated towards the use of motorised transportation. Plate 3 is an aerial photograph of the

Oмили low cost housing settlement in Lae. It is obvious that conventional Australian-conceived suburban planning has provided the model, and that, implicitly, the key determinant of the layout of this housing settlement was access to the household door for privately-owned motor vehicles. Data presented in this report show that while Papua New Guineans' ownership of private motor vehicles has doubled between 1972 and 1976, it is levelling off at only 2,500 out of a total population of 2,900,000 people in 1977. Clearly, many of these cars are owned by residents of high covenant housing in towns and cities, whilst much less than 5% of low cost housing commission dwellers own cars now, or are likely to own cars in the foreseeable future. So the construction of roadways giving access for motor vehicles to each house is a considerable waste; at least 15% of all land in existing housing commission settlements is used for roadways. All that is required is public transport access to the periphery of conveniently sized blocks under settlement, with a foot and bicycle path network leading off it and servicing, ultimately, individual houses. Only minimal parking space is required on the periphery for private vehicles or institutional vehicles on loan. The rest of the land could be used for allotment gardens, play areas, communally allocated zones for meeting halls, resource centres, health centres and the like. This alternative pattern of development, of access roads for heavy transport and public motor vehicles to the periphery of settlements, and foot and bicycle paths within, permits a use of space which allows maximum expression of culturally compatible patterns of social interaction, and socially optimum use of valuable ground for gardens and for play areas away from the constant danger of interruption by high-speed motor vehicles.

This returns us to the fundamental point of social equity in the distribution of resources. In the present mode of urban planning, a large portion of land with high opportunity cost and with a significant share of community taxes invested in it, gives maximum benefit to the very few people who use private motor vehicles. Our data show that 20% of the population use their legs for transportation outside of, and perhaps 90% within, the settlement areas, and that 55% use public motor transport. To a limited extent, these populations are interchangeable for, as our research into domestic patterns of

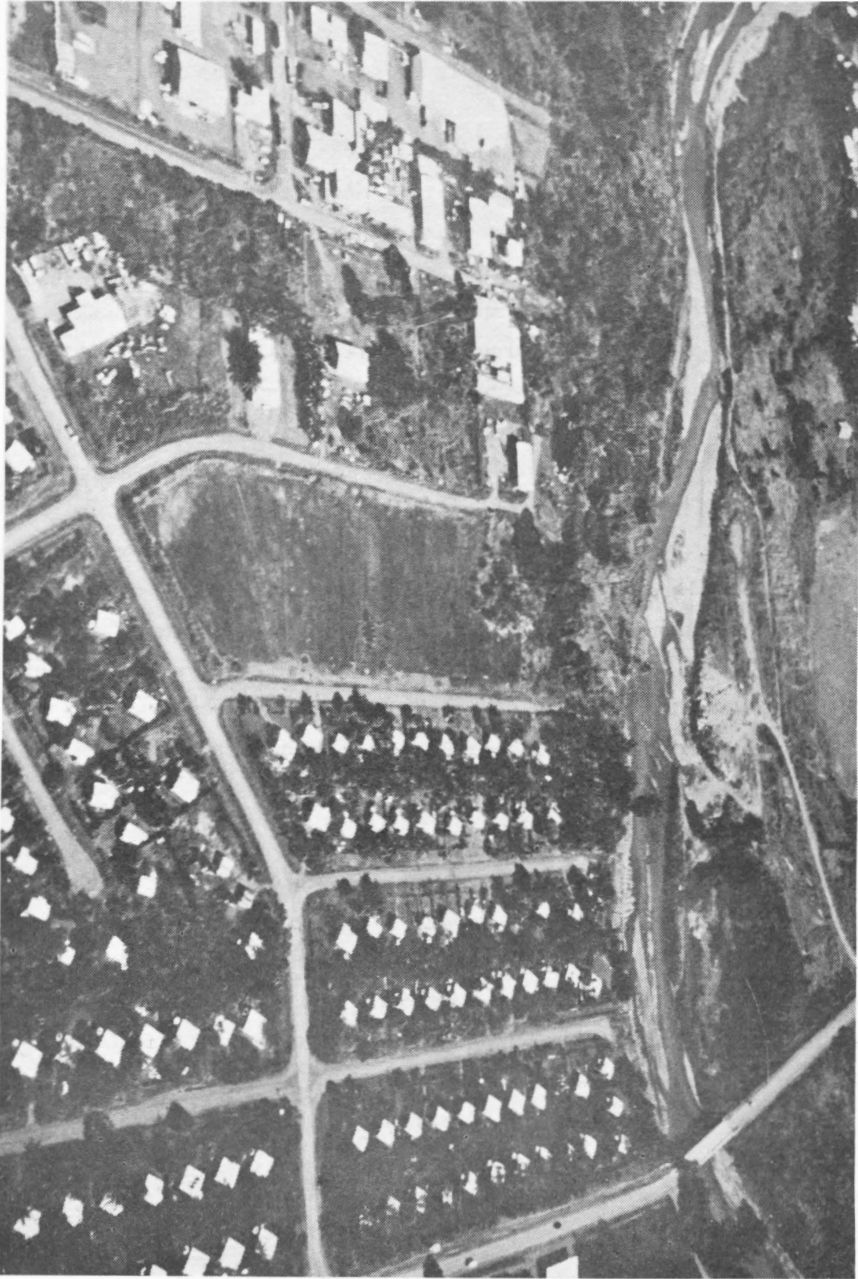


Plate 3 Aerial photograph of the Omili low cost housing settlement,  
Lae, 1977



energy use shows, people walk or take public motor vehicles as often as determined by their present financial circumstances. However, data presented in Table 8 show that only 7% of walkers 'usually' take passenger vehicles.

As part of the Papua New Guinea Human Ecology Programme a proposal was drawn up for the Lae City Council (Newcombe and Bowman, 1978) which detailed informal footpath networks, and recommended policies to augment facilities for foot and bicycle traffic. The expenditure programme proposed included co-operation with local industry in the promotion of bicycles. One industrial group ARC-TITAN, a steel fabricating company, already operates a subsidised bicycle purchase scheme, encompassing the use of bicycles as an alternative to using trucks to pick up employees (except during inclement weather). Other industries have agreed to join this scheme if the Lae City Council adopts a pathway construction programme and publicity promotes the use of bicycles. Industry would also be invited to sponsor bike racing in the Morobe Province. In July 1978, the Lae City Council allocated K20,000 (US\$29,000) for foot and bicycle pathway construction for the following six months. This should mean the construction of about 3kms of footpaths and bicycle paths during that period.

#### Conservation of transport fuels

Of course, our capacity to conserve transport energy depends on the human habitat we have designed. For example, the relative spacial location of homes, gardens, industry, shops and commercial services, markets, school and recreational facilities is a key determinant of the amount of transport energy needed for a local resident to utilise any of these facilities.

In the previous section we stressed the importance of improving facilities for the use of muscle energy and for giving status to muscle-driven forms of transportation. It is also obvious that the further the distance between urban facilities important to survival and human well-being the higher the energy cost of subsistence, and the greater the dependence on imported energy forms just so people might interact with their environment to secure their survival. Clearly then, the planning of housing settlements must consider not only the

internal arrangements of houses vis a vis one another, but also the spatial relationship that the housing settlement bears to the rest of the urban settlement. To plan with the resource and social costs of traversing distances in mind is to take an initiative adaptive to a future in which the cost, or even the absolute availability, of appropriate transport fuels will severely penalise dispersed human settlement patterns. This is a penalty the poor on the urban fringe will pay more heavily than the rest of the urban population (Newcombe, 1978).

It is also important that urban settlements be designed so as to reduce the demand of the urban population on expensive imported commodities and to facilitate to the greatest extent possible balanced rural vis a vis urban development. If urban settlements are designed in such a way that people cannot do without motor transport this will mean less energy will be available for agricultural development in the rural areas. It is obvious that, if properly planned, the latter is the most productive use of scarce energy resources.

Sensible forward planning of settlements allows the nation to take maximum advantage of more simple conservation measures such as increasing the energy efficiency of motors, and increasing the occupancy of vehicles. So great is the use of motor transport in the United States that an increase in the average efficiency of motor transport by one mile per gallon will decrease the national energy use for all purposes by 1% (AIP, 1975). It can be calculated for the Lae urban ecosystem that increasing the fuel economy of trucks from 1.8 K/l to 2.0 K/l would save 5% of total road transport fuels. Even though 1% of U.S. energy use is 400 times the energy use of Lae, in terms of the Papua New Guinean economy a 5% reduction in road transport energy use would be a significant gain in overall self-reliance.

We have been quite explicit in previous sections that a rapid growth in private car ownership is not a desirable trend from the viewpoint of equity in the public consumption of taxes embodied in the transport system, or in terms of the social costs of high-speed motor transportation in residential areas. It is also clear that as a transport mode, the private car uses a disproportionate amount of energy to carry people over the same distance when compared with public motor vehicles. For instance, private cars in Lae use roughly

twice the amount of energy to transport half the people carried by public motor vehicles. The implications of a shift of only 2.5% of the public motor vehicle population to private motor cars at their present occupancy and fuel economy is that the energy cost of personal transport will increase sevenfold by the year 2000. The cost to the country in strategic terms, or in terms of foreign exchange, could be considerable for what amounts to an inefficient use of resources by an elite. We have found this to be the case already in Hong Kong (Newcombe, 1979).

Disincentives for the use of private motor vehicles can come through increased taxes on petrol and increased registration costs. In addition, the energetic efficiency, or fuel economy of imported private motor vehicles and industrial and commercial vehicles should be regulated by Government.

The average occupancy rate of public motor vehicles of 8.5 is also very low compared to an upper limit of, say, 25. In Hong Kong the equivalent transport form of mini-buses achieves a load factor of, on average, 71.4%, which would be equivalent to between 18 and 20 persons for the public motor vehicles in Lae (Newcombe, 1975). The Hong Kong load factor was obtained by tight control on the number of vehicles licensed to carry passengers and was based on constant monitoring of vehicle occupancy and of the effectiveness of public motor vehicles as a transport mode. Such control would not only increase the energetic efficiency of public transport in Papua New Guinea, but would ensure the economic success of local entrepreneurs in the public motor vehicle business.

One final point about energy conservation in transport is that it should begin at home. The Papua New Guinean Government in its various forms, has 780 vehicles in its Lae fleet. Government energy use is almost 10% of total end-use of road transport fuels in the Lae urban area and apart from the savings it could initiate by careful buying and vehicle use, it sets a poor example for the development of a sustainable future. Our 'street corner' observation routine led us to the view that government employees use of motorised transport was unrestricted and without regard to the expense of the fuel or of maintenance costs. This is a pattern learned by example from the Australian administration and one that is passed on readily to the use

of industrial and commercial vehicles, and can lead to an unnecessary reliance on private motor cars for personal transportation.

It seems prudent to re-evaluate the need for present levels of motor vehicle use in government, department by department, and to investigate the introduction of pedal vehicles wherever they match the end-use requirements for transport.

### Alternative transport fuels

Once again only those alternative fuels which are locally available and renewable will be considered here. The following are, by this definition, potentially viable alternative energy sources for transport in Papua New Guinea; power alcohol, charcoal, palm oil, electricity, hydrogen and methane gas. Table 26 presents these fuels in respect of their origin, availability and potential end use.

#### Palm Oil

The oil that can be extracted from the kernels of a number of palms (e.g. Elaeis Guinllusis, Orbignia Martinana, "Babassu Palm") can be used alone, or in blends with diesel in diesel engines. Brazil has already demonstrated this potential by extracting the oil of its Babassu palm for this purpose. In the North West of Brazil there are forests with naturally occurring stands of Babassu palm which when tended regularly provide improved and regular yields of kernels of 10 to 15 tonnes per hectare. Plantations of Babassu palm, grown for energy farming, yield at least 30 tonnes per hectare. Brazil has a present production of 4 million tonnes of kernels and a planned production for 1985 of 40 million tonnes. Each tonne of kernel yields 75 litres of ethanol, 40 litres of oil and 150 kg of charcoal, thus the Brazilian target production is for 3,000 million litres of ethanol and 1,600 million litres of oil from Babassu palm by 1985 (Stumpf, 1978).

The Dutch botanist and agronomist Van Meulen, pioneered the use of Babassu in Indonesia and then in Brazil. His claim is that if grown successfully on otherwise low-productivity grasslands, called

TABLE 26 ALTERNATIVE TRANSPORT FUELS

ENERGY FORM	ORIGIN IN PNG	CONVERSION TECHNOLOGY	TECHNOLOGY OF END-USE	SUITABLE TRANSPORT END-USE	COMMENTS ON POTENTIAL
Palm Oil	Palm Tree sp. (eg Babassu palm)	Oil extraction equipment	Unmodified diesel engine	ships, trucks, trains and buses	Costs as a fuel yet to be established through industry already exists producing oil for food at 29t/litre FOB PNG.
Charcoal - producer gas	Wood wastes, Firewood plantations	Kilns, retorts	Producer gas coupled to petrol engines	Trucks, buses and trains	Proven technology, costs to be established for PNG for this end-use, though full costs are 11t/litre of petrol equivalent.
Alcohol fuels (ethanol and methanol)	Notably Cassava, sugarcane, wood Nipa and Sago palm	Yeast in fermentation towers, or wood gasification to methanol	Unmodified and modified petrol, diesel and jet engines.	Cars, trucks, buses (aircraft?)	Proven technology, costs for mass production 16t/litre for alcohol from molasses CIF LAE, 25-30t/litre for cassava derived alcohol.
Hydrogen	Electrolysis of water with hydro-power	Electrolytic cells	Direct combustion internal modified combustion engine or electric motors through fuel cells	Aircraft and road vehicles	Commercial technology not available, perhaps 5-20 years.
Methane Gas (Biogas is 60-70% methane)	Sewerage & other organic waste	Bioconversion chambers for anaerobic decomposition	Standard internal combustion engines with modified fuel feed systems	All road vehicles	Proven technology, costs competitive in PNG. Soon to be demonstrated.

Kunai grasslands in Papua New Guinea, and that planting with Babassu palm can be the first step towards the recovery of these grasslands for combined agricultural and forestry uses. There are vast areas of Kunai grasslands in Papua New Guinea which represent a terminal state, under present geological and climatic conditions, after continued firing of tropical forests in both the highlands and the lowlands. The loss of these forests represents a serious decline in overall productivity and carrying capacity, especially on steeply sloping country, and is a sign of marked imbalance in man-environment interaction in these ecosystems. The retrieval of these now impoverished grassland ecosystems to states of high and sustained yields of energy and agricultural products would be a transition of great significance to Papua New Guinea and a boost to its present pronounced policy of rural development.

Apparently there has been no experience of Babassu palm within Papua New Guinea, and so its potential as represented here remains speculative, based on its performance in other places. There is every reason to investigate its use in Papua New Guinea for the gains that can be made are considerable whilst, if a failure, the effort lost is minimal. Babassu palm does not yield kernels of any volume until its 8th year, so a careful long term programme would have to start soon if this resource is to make an impact on transport energy needs in a decades time.

The Philippine researcher Cruz (1978) has demonstrated the use of coconut palm oil in diesel engines. He has shown that unrefined coconut palm oil is combusted with as high an efficiency as distillate when burnt in an unmodified diesel motor. The present price of coconut palm oil makes this practice prohibitively expensive in Papua New Guinea when the FOB price for coconut oil is 29t/l (A. Shepherd, Department of Primary Industry, pers. comm. 1979). However the use of a blend of coconut oil and ethanol in 1:10 ratio is likely to be economic for outboard motors in the Sepik River areas where a full feasibility for sago-alcohol will proceed in 1980. Here the high cost of coconut oil would have a very small impact on the price of the oil-ethanol blend.

## Charcoal

Charcoal fired producer gas units have been used in many countries when oil shortages have occurred due to war or economic disruption. Conversion units gasify charcoal in the vehicle and feed the gas to a conventional gas combustion engine. The minimum weight of a conversion unit is about 100kg which limits their use to public motor vehicles and trucks rather than to private cars (Earl, 1975, p.36). One tonne of charcoal is equivalent to 720 litres of petrol under normal conditions. For the usual three tonne trucks and public motor vehicles operating in Papua New Guinea this means that 100kg of charcoal would be enough for journeys of 220 and 384kms, respectively. Charcoal-fuelled vehicles would be particularly compatible with the development in rural areas of either small pyrolytic converters, or charcoal kilns or retorts to convert dispersed forestry or agricultural wastes to charcoal. Hundreds of small charcoal manufacturers could sell their produce to dealers along the major highway routes. Generally the energy source should be a waste of little value or else wood from dedicated short rotation eucalypt forests. At K75 per tonne for charcoal, a price which guarantees a fair return to small holders, the price of the equivalent of a gallon of petrol would be 50t, compared with a real price for petrol delivered to rural areas of from 2 to 10 times that amount. Earl (1975) also reports the fact that Sweden operated 100 trains on producer gas units in the early 1940's and points to the obvious possibility of cheap train systems in those developing countries which have adequate raw materials for charcoal production.

There has been a recent revival of interest in portable producer gas units for cars and trucks, as well as a re-evaluation of the costs of retrofitting gas/oil boilers with gasifiers for wood or biomass fuels (Reed et al, 1978; Bailey, 1979). The thousands of gasifiers which operated during World War Two in Europe were, however, fairly crude devices. According to the scientist who had responsibility for the British producer gas programme during the war, Professor Thring of Queen Mary College, London University, the acid tars and oils (pyrolytic fuels) in the gas condensate had a disastrous effect on engines, greatly reducing their life (pers. comm. S. Joseph, ITDG, London, 1978). Commercial units are available from Switzerland

(Roth Co.) and from Japan ('Checoco' gasifiers), and there is a great deal of research now into gasifiers using 'downdraft' units, which clean the pyrolytic off-gases as they pass back through the bed, alleviating the corrosive effects on engines. Research is being conducted at Pegasis Co, Washington, on these new producer gas units and at Davis, California (using walnut shell feedstock) to produce a crack pyrolysis gas for transportation. Here the off-gases are produced from a bed fed with oxygen and not air, effectively removing Nitrogen from the gas stream and increasing the energy density of the off-gas to 0.81 MJ/kg, about double normal producer gas. This higher energy density makes gas storage more economic (Goss, 1978). Both Volvo and Saab have experimental versions of efficient clean producer gas units (Volvo, pers. comm. 1979). The problem of engine derating has not been solved for the new technology. Volvo reports a 50% power derating for Volvo sedans. In the highlands of Papua New Guinea a partial loss of power will be a serious practical and cultural problem facing the introduction of producer gas units for transportation. However, in the flat coastal regions of Papua New Guinea the producer gas units (down-draft versions) are likely to be an attractive option with coconut palms and shell converted to charcoal as the fuel.

#### Alcohol fuels

Ethanol and methanol can be produced from any organic feedstocks containing either sugar, starch or cellulose. Ethanol is produced from the fermentation of sugars, commonly from sugarcane juice or molasses, the traditional sugar industry byproduct, but also from cassava, sorgham, maize, sugar and fodder beet and all grains. In the basic starch feedstocks enzymatic hydrolysis is required to convert starch to sugars for fermentation. Ethanol can also be produced by acid hydrolysis of the cellulose in wood. In Papua New Guinea, in addition to most of the above mentioned feedstocks, sago palm (*Metroxylon* spp.) and Nipa palm (*Nipa Pruticans*) can be utilised because of their high starch content on the fermentable sugars in their saps (Hutchinson, 1941; Foxworthy and Mathews, 1917; see also Chapter 2).



Alcohol fuels can be burnt as mixtures with conventional transport fuels or directly. Ethanol and methanol can be burnt in mixtures up to 25% with petrol in standard spark ignition motors without modification, and pure alcohol burning engines have been designed and tested by Volkswagen, Ford, Fiat, Volvo and Chrysler in Brazil (Stumpf, 1978a; Koenig et al, 1978; British Consulate General, Brazil, 1979). Alcohol blends are feasible for compression ignition or diesel engines as well, despite claims that the hygroscopic nature of alcohol fuels, and their poor lubricity, makes them unsuitable for this application. A combination of 80% ethanol and 20% diesel oil have been operated, knock free, with the alcohol being introduced via a carburetter, and the diesel oil by injection. Trouble free operation is assured at 40% alcohol and 60% diesel under this system (Stumpf, 1978a). In New Zealand there is confidence that a 90% alcohol and 10% diesel mixture can be operated successfully and tests on 95% ethanol in 'dual-fuel' diesel motors are proceeding in West Germany under the supervision of the German Ministry for Research and Development (NZERDG, 1979; Plassman and Bandel, 1979).

Alcohol fuels have been used for transportation many times during this century in Europe, United Kingdom, Australia, United States and Brazil. Sweden sold a 25% ethanol blend for ten years during the 1940's and 1950's, called "lattbentyl" (Pleeth, 1949). In Australia in the early 1940's a Senate Select Committee recommended large-scale expansion of alcohol fuel production from plant material and it was compulsory to have at least 1.5% alcohol in petrol sold in Queensland (Commonwealth of Australia, 1941; Hutchinson, 1941). The Shell company sold a 20% ethanol blend in Queensland and New South Wales during and after the Second World War (pers. comm. Shell, Papua New Guinea). In all instances the production of alcohol fuels ceased because of the availability of cheap petroleum products in the 1950's and 1960's. However, since the oil crisis in 1973-74, the price of petroleum products has risen to the extent that alcohol fuels are regarded once again by many countries as a viable medium to long term option.

Brazil began its National Alcohol Programme - NPA in 1975. In that year it produced 414 million litres of alcohol, 36% of which was fuel. In 1976, alcohol fuel production was 800 million litres, and

in 1977, 1,127 million litres progressing towards a target production of about 3,000 million litres for fuel in 1982 (Hammond, 1977; Yang and Trindade, 1978; Stumpf, 1978). Since June 1977, the City of Sao Paulo, with 1 million vehicles, has operated on a 20% blend of ethanol in petrol and a demonstration fleet of 300 volkswagens operate on pure alcohol. In 1978 the 20% blend was extended to several other major cities reaching 11% across Brazil on average in that year. Alcohol production in Brazil has traditionally been from molasses and linked to the size of sugarcane production for the world market, but now sugarcane juice is being converted to ethanol from over-production sugar and the major alternative alcohol crop, cassava (Manihot esculenta, Crantz) is being investigated. Brazil is already the largest producer of cassava in the world and the move to cassava-alcohol is logical in terms of its need for rural development. Start-up tests were run in early 1978 on the world's first major cassava-alcohol plant, a 60,000 litre per day facility. The cost of cassava-alcohol at the service station in early 1978 was estimated to be the same as petrol (taxed price) at US\$1.62/gallon, compared with sugarcane alcohol at US\$1.50/gallon and the alcohol fixed price at US\$1.34/gallon; this latter figure being based on molasses production. Early problems with the curvelo cassava-alcohol plant appear now to be solved (Novo Industries, 1979). These problems included both supply of tubers and starch separation and hydrolysis deficiencies.

The Brazilian programme is a valuable indication of the potential of alcohol fuels for Papua New Guinea. Current 1980 prices for petrol in Papua New Guinea are 29t/litre (K1.32/gallon, US\$1.91/gallon) at mainports and an average of 35-40t/litre in real terms for the entire hinterland, with prices as high as K1.00/litre in some very isolated areas. Generally cassava is the most attractive early option as a dedicated alcohol fuel crop for Papua New Guinea, although the alcohol fuels potential of sugarcane and forestry waste products are very significant (see Chapter 2). Following the indication of potential expressed in the earlier version of these transport papers (Newcombe et al, 1978) a cassava-alcohol industry was examined for the highlands region of Papua New Guinea. After a year of preliminary, then detailed investigation, a two million litre per annum cassava-alcohol industry for the Baiyer River area of the Western Highlands Province has been initiated between the newly formed Energy Development

Company of Papua New Guinea, and Davy Pacific of Melbourne, Australia (see Newcombe et al, 1980).

This facility will cost K1.78 million (1979 Kina), and shows an IRR of greater than 15% with the most likely starting price of 30t/litre for ethanol at the factory gate in the third quarter of 1981, the start-up date. This facility is proposed by the Department of Minerals and Energy as a pioneer for smaller, rather than larger industries, a strategy compatible with both the national energy strategy and the country's development strategy. The ethanol produced will be blended at 10-15% in motor spirit at service stations in Mt. Hagen, 40 kilometres away, for regional distribution. The pump price for the blend will be 6-7t/litre higher than the factory gate price.

During 1980 two major feasibility studies will be conducted, one in the North (Markham Valley) and one in the South (Port Moresby region) on sugarcane/cassava alcohol complexes to feed 6-15 million litres/year industries for the mainports of Lae and Port Moresby, and distribution points beyond. Early indications are that ethanol can be produced for about 22t/litre at the factory gate for a 10 Ml/year industry. Both facilities are planned for full production by late 1982.

A 30,000 tonne per annum sugar industry is planned for the top-end of the Markham Valley which extends out from Lae. If this industry proceeds then 4.2 million litres of alcohol could be available from molasses at 16t/litre CIF to Lae each year from 1983 onwards (Bookers International, 1978). This price is very favourable to a blending programme at today's (1980) petroleum prices.

In addition to the molasses-alcohol from this sugar industry, alcohol production could be augmented in two ways: sugarcane juice alcohol from over-production, or dedicated sugarcane to alcohol production and a cassava-sugarcane complex. Ethanol from over-production cane, including tops, can be produced in the Bundaberg area of Queensland for about 10t/litre raw material costs (Bull and Batstone, 1978). It is likely then, that over-production cane from the Markham Valley could produce alcohol for about the same costs as from molasses, at 16t/litre at Lae. A 10% over-production of cane from a 30,000 tonne/year sugar industry would yield 21,000 tonnes of excess cane, or about 1.7 million litres of ethanol.

The second option, of combined cassava and sugarcane cropping, is attractive because it makes better use of existing distillery facilities and of the excess bagasse from sugar production, which can be used for fuel for distilling cassava alcohol, if necessary. Distillery facilities are usually only in use for half the year at solely sugarcane processing plants. If cassava were produced to the level at which the distillery capacity was fully utilized, a further six million litres of alcohol could be produced (distilling capacity minimum of 12 million litre/year), requiring 1200 hectares of cassava cropland. Projected costs of ethanol from this kind of combined operation in Queensland are about 6t/litre (1978 Kina) for raw material costs. This ethanol is likely to be competitive with conventional transport fuels at main ports in Papua New Guinea (Bull and Batstone, 1978).

The other main option for ethanol or methanol production for Lae, and indeed for Papua New Guinea as a whole, is to use wood as a feedstock. New Zealand and Brazil are amongst the most advanced countries in evaluating the wood-alcohol option, for each has thoroughly investigated the potential for achieving long term self-sufficiency in transport fuels (CTP, 1979; NZERDC, 1979; DSIR, 1978). The New Zealand Energy Research and Development Committee recommended for immediate progress towards the operation by 1982 of a 50 ODT/day wood gasification methanol plant leading to a fully commercial 500 ODT/day plant by 1987/88 (NZEDRC, 1979). Brazilians will have a 30 ODT/day and hydrolysis plant producing ethanol from wood at Lorena by mid-1980, and expect that commercial operation of the 30,000 litre/day level will follow. The State of San Paulo will have the first of four 100 ODT/day wood gasification to methanol plants at Jupia by mid-1981 (Newcombe, et al., 1980).

It has been estimated for New Zealand that one half-million ha plantation of high-yielding forest species could provide all of New Zealand's transport requirements by the year 2000 (Cousins, 1978).

This New Zealand and Brazilian progress is of considerable importance to Papua New Guinea because, as indicated in Chapter Three, within the Lae region in 1978, sawmills generated about 72,000 ODT/year, virtually on a sustainable basis<sup>1</sup>. If non-renewable industrial-commercial energy demand was met entirely from these wood-wastes, 29% of this resource would be utilized by 1985 and 60% by the year 2000. If we regard the wastes remaining after conversion by pyrolysis to industrial fuels as available for alcohol production, we have 106,000 ODT available in 1985 and 60,000 ODT in the year 2000. Wastes collected from the forests are available for K24/ODT, and those at the saw mills for about K5/ODT, chipped ready for conversion (M. Page, Forest Conversion Technology, CSIRO, Victoria, Pers. Comm., 1978). Using recent costings of the wood-hydrolysis to ethanol route supplied by Dr Brian Earl (Chemical Engineering, University of Canterbury, New Zealand) observing economic trade-offs between size of production and forest wastes in the field can be converted for about 20t/litre, which is roughly the same cost as the first quarter of 1979 petrol prices at the main ports in Papua New Guinea.

Because the mass production alcohol technology is only in the early developmental stage, the earliest time that a conversion facility can be put on line in Papua New Guinea is

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<sup>1</sup>From total forest wastes and culls of 2,310 ODT used over 30 years.

likely to be in the 1985-1990 period. Thus, here we will not consider alcohol as available from this source until after 1990 in our estimates of renewable energy supply to Lae, but, 52 million litres will be considered available in the year 2000, representing the then surplus wood-waste of 60,000 ODT per annum when converted at 50% energy efficiency to ethanol.

In the 1990's we believe that the price of growing wood just for conversion to alcohol will be competitive with imported petroleum and probably not significantly different from the price of alcohol produced from wood-waste. Eucalypts (E. grandis, E. robusta) are now produced in the Wahgi Swamp in the Western Highlands of Papua New Guinea for K15/ODT, which is the price including royalty at which this wood is available from nearby tea factories for fuel. Since the crop would be systematically laid out and managed for efficient harvesting, with yields of between 20-40 ODT/ha/year, the transport savings of this option over scavenging for wood-waste would probably compensate for the fact that the wood-waste is free. Leucena leucocephala (var. giant) is a good species for ethanol production in the lowlands (NAS, 1977). Poorly managed Leucena crops have already yielded 15 ODT/ha on gravel-laden soils at the University of Technology. Short rotation forests (Leucena or Eucalypts) ought to yield alcohol for 25-30t/litre at the pump in 1978 Kina terms, by the 1990's, for these are the costs being suggested for 50 million litre production facilities for cassava, sugar-cane and wood, today (Smythe, 1978; McCann and Prince, 1978; Earl, 1978; Whitworth, 1978). This means that by the 1990's the entire road and sea

transport energy requirements of Lae could be economically met by alcohol fuels, if the price of imported fuels is 1.5 times the present price in real terms and all-alcohol engines were commercially competitive with conventional petroleum engines.

Although alcohol fuels could theoretically satisfy most of the demand for transport energy in Lae by the year 2000, strategically, it will be sound to distribute some of the alcohol fuels produced in the Morobe Province to the nearby highlands or coastal areas. In other words, the potential for the Lae region to become self-sufficient in transport fuels is merely to be regarded as an indication of the viability of a renewable energy strategy for Papua New Guinea as a whole.

### Electricity

Electric cars have already been developed in many countries, including Australia, and are a regular component of the urban transport fleet in London (Bockris, 1974). The energy cost of an electric motor vehicle depends on the means of generating electricity to be used. With hydropower, the energetic efficiency of electric cars is at least five times that of petroleum driven vehicles (Netschert, 1970). However, the costs of the electricity vis a vis petroleum products is the ultimate determinant of the economic viability of electric powered vehicles. We anticipate the costs in Papua New Guinea on a petrol equivalent basis to be between 56 and 152 toea (Aus. 67¢ to \$1.82) per gallon (K1 = A\$1.25 = US\$1.45).

The use of electric vehicles would be restricted to urban areas because the effective range of current designs is of the order of 80kms per day. Any large-scale adoption of electric vehicles in an urban transport system could have advantages for load distribution in electricity generating facilities if electric vehicles were mostly to be recharged overnight. For both economic and social reasons the use of small electric vehicles in the Papua New Guinea Public Service would appear to warrant further investigation.

### Hydrogen

The hydrogen economy is frequently spoken of in glowing terms (Gregory, 1973, Bockris, 1975) even though it is undoubtedly decades from realisation. Hydrogen is an ideal transport fuel and can be either combusted directly in modified internal combustion engines or it can be used to produce electricity in fuel cells and thereby to drive electric motors. The main problems are safety and bulk in storage. Safety is alleged to be a problem of the order of that for handling natural gas when the hydrogen is used and transmitted in gaseous form. However, cryogenic liquid hydrogen storage is apparently expensive and potentially dangerous, whereas the bulkiness of storing it in gaseous form is currently an impediment to motor transportation. Nevertheless, technological options have been identified which may alleviate both problems and the fuel cell and hydrogen storage technology research is increasingly promising (Maugh, 1972, 1972A). Even so, there is little doubt that any option such as electric vehicles, which requires a radical change away from the present internal combustion engine and related distribution systems for transport fuels, will not be a significant alternative this century in Papua New Guinea.

### Methane gas (biogas)

A very practical though strictly limited near term option for transport and for industry is methane gas from digestion of urban sewage and organic wastes. Biogas production from bioconversion of sewage has long been a part of the operation of conventional sewage treatment plants in developed countries, although gas production has not been the central goal of such sewage treatment plants, and there has rarely been a net energy gain from these operations. Sewage treatment geared to surplus gas production and to biologically productive waste treatment has now been proposed for city-wide sewerage systems (Newcombe and Bowman, 1978, Newcombe and Nichols, 1978). Pilot plants for generating gas from the effluent generated by large pig populations have been constructed in densely populated areas of Singapore (McGarry, pers. comm., IDRC, 1977). Recently, a simple large-scale biogas plant has been built and operated successfully at the Canberra Abattoirs, Australia (J. Coulthard, Sanamatic Tanks,



N.S.W., pers. comm., 1978). The methane from this plant is being used to drive petrol and diesel car and truck engines using a cheap and simple dual fuel system. Although with pig and poultry manure as a feedstock the stripping of  $H_2S$  from the gas to be used in transportation is desirable because of the otherwise great potential for corrosion of motors, this is reported to be a less severe problem with bioconversion of human sewage. The gas generated in the Lae system will, then, be used direct, and careful monitoring of motor wear will take place.<sup>1</sup> If a problem is observed then iron filings scrubbers will be installed. Similarly, because compression will only be to 450 psi,  $CO_2$  need not be stripped from the biogas. This latter technology provides a useful working model for the development of a similar system of sewage disposal in Lae which has now been designed by Coulthard (Sanamatic Tanks) for the Department of Minerals and Energy and the Lae City Council as an outcome of this research (Coulthard, 1979).

A Sanamatic system of 61,000 gallons capacity has been constructed at the Taraka Sewage ponds in Lae. This will convert into methane gas and fertilizer, primarily nightsoil from the city, but also primary solids from the Taraka sewerage system, and paunch gut waste from the local abattoir. The gas product shall be  $710 M^3$  net per day, the equivalent of 500 litres of petrol. It will also yield 6,000 gallons of liquid fertilizer (1% N), and 1.5 tonnes of sludge per day. The gas will be compressed to 450 psi and used in Lae City Council light trucks; the liquid fertilizer will be sold at 75% the price of commercial nitrogen fertilizers (CIF, farm gate), and the sludge will be incorporated into the city's composting programme (also arising out of this research). If the gas is valued at 22t/litre of petrol equivalent and it takes four years for sales of fertilizer to reach 90% of production, starting at 10% in the first year, then the internal rate of return on investment exceeds 25%.

As an energy source, methane gas is not significant in urban Lae. Converting half the sewage of the Lae population, probably the

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<sup>1</sup>We have now decided to scrub the gas using a water tower with telorets. Most of the  $CO_2$  and  $SO_2$  will be removed in this way (Newcombe, July, 1980).

maximum amount that is achievable, the gas yield is about 1% of the 1980 demand for transport fuels. However, the real value of the bio-conversion process is in its main product of high quality, pathogen-free fertilizer from a pathogen-rich waste source as part of an integrated nutrient cycling-intensive food production system for the city.

### Discussion

This research has led to a detailed assessment of the patterns of transport and their energy requirements, both muscular (somatic) and fossil-fuel-derived (extrasomatic) for the Lae urban area for 1976-77. Pedestrian traffic has been shown to be an important, but neglected, transport mode for both social and energetic reasons and the conclusions of previous investigators (Commission of Enquiry, 1975; Taylor and Assoc., 1971), which recommended the bicycle option, are once again supported. We also believe that there is an important, though subtle, interplay between social and biological well-being and the design of the city in respect of access to facilities important for subsistence such as, markets, gardens, employment, recreation and education facilities. The present Australian suburban layout levies penalties of time and distance on the low-income settlement dwellers at the urban periphery by making walking or cycling difficult and dangerous. Similarly, motorised transport networks are imposed on densely populated areas, regimenting urban designs when the utility of the motor vehicle is clearly marginal and when functional social and biological relationships are critical to smooth the transition from village to urban society.

On the other hand we do not hold that motorised transportation is an unnecessary evil; indeed the liberating effect of the Public Motor Vehicle on village society is immense and its resource costs can be well afforded. Sensitive urban design can facilitate, rather than preclude, the evolution of a transport system compatible with social and biological requirements for well-being. It is interesting to observe that in settlements where choice was possible, footpaths rather than roads are the access routes (e.g. in the design of the Boundary Road settlement).

Apart from the impact of transport systems on the social fabric of the community, our data show that the energy cost of a rapid transition to the private car, which is encouraged by present urban planning, is great, and will impose a significant and, in terms of mere mobility, unnecessary energy dependancy on the community. In one sense it makes little difference whether this energy demand is met from imported or renewable energy sources since both will be expensive and, ultimately, limited.

The evaluation of locally available renewable energy sources for Lae, in the quest for regional self-sufficiency should really be viewed in the wider context of obtaining energy self-sufficiency for Papua New Guinea as a whole, for while registering the potential for an all renewable energy supply for Lae is a useful exercise for this study, it is not, in itself, a realistic energy development objective for the country. Nevertheless, Lae was chosen as the target city for this study because of the parallels between problems faced there and those faced in other urban areas in Papua New Guinea (and their hinterlands), and it appears true of energy policy and planning that solutions, or options, for Lae indicate useful directions for much of Papua New Guinea.

It is apparent that the main alternative transport fuel is ethanol produced from a variety of feedstocks. Table 27 shows the proportion that alcohol fuels could represent of total road and sea transport demand for Lae up to the year 2000. This potential is related to the time when each of the options is likely, in our estimation, to be technologically feasible and economically viable for Papua New Guinea. By integrating alcohol production with other industries, notably sugar and forestry, yields in the Morobe Province, or the immediate hinterland of Lae, could represent 50% of the specified transport fuel requirements during the 1990's. Here it is assumed that by the mid to late 1990's it is likely that imported petroleum prices will be such as to make dedicated fuelwood cropping, with alcohol as the major product, an economic proposition. At this time it will be possible to grow sufficient biomass within a 30 mile radius of Lae to meet the deficit in alcohol fuels from other sources. Given a possible yield of 5,000 litres of alcohol per hectare for

Table 27    THE POTENTIAL OF ALCOHOL FUELS AS AN ALTERNATIVE  
TRANSPORT FUEL FOR LAE, UP TO THE YEAR 2000

(Million litres)

	Demand for transport fuels (1)	Equivalent in alcohol fuels (2)	Potential supply of alcohol fuels (3)	Alcohol fuels as % of total demand
1977	25.1	31.4	-	-
1980	31.8	39.8	-	-
1985	46.0	57.5	14 - 42	24 - 73
1990	69.9	87.4	14 - 42	16 - 48
1995	103.3	129.1	66 - 106	51 - 82
2000	153.5	191.9	106+	55+

Weighted average energy value/litre of 36.4MJ

- (1) Based on 3% per capita growth in demand, and 5% growth in population, per year. Includes only road and sea transport energy demand.
- (2) Assumption is that alcohol fuels have 'effectively' 80% the energy value of the diesel and petrol they replace.
- (3) 4.2M litres from molasses by 1985, plus over-production sugar, 1.7 litres, plus 6M litres of cassava-alcohol.\* By 1995, 52M litres of wood alcohol is available.

\* By 1983 between 10M litres of sugar/cassava alcohol may be available from Markham Valley production.

cassava, sugarcane or forest crops, 17,000 ha of additional crops in 2000 would satisfy the deficit shown in Table 10.

In addition to alcohol fuels there are other less important options during this 22 year period, such as biogas and producer gas, which will be demonstrated but which are unlikely to be adopted as readily as the alcohol fuels option. Electricity for transportation, or the hydrogen fuel that may be derived from it, are definitely capable of supplanting all petroleum fuels in the longer term, post-2000. However, as with Brazil, despite massive hydro-potential and hence a huge hydrogen fuels potential, the end-use technology and related management and delivery systems are much less known at this stage than for alcohol fuels, which are already in widespread use. Judging then, from today's technology and known patterns of transportation, it seems wise to vigorously pursue the alcohol fuels option and to continually review the progress in electric vehicles and hydrogen powered vehicles research in case important breakthroughs favour earlier development of this option.

The unsolved component of transportation with respect to alternative fuels is air transport. Aviation fuels account for 17% of the transport energy flow in Lae and assuming that the same proportion is maintained to the year 2000 the aviation fuel demand will be three times the 1977 demand for all transport fuels. Only in Brazil are there light planes and helicopters designed to operate on ethanol (Newcombe, et al., 1980), whilst the rise of hydrogen as an aviation fuel had a short and disastrous history with the Hindenburg disaster, and has not been revived since. The low prospect of alternative fuels makes conservation of conventional aviation fuels all the more important. The evaluation of energy conservation potential made by New Zealand scientists suggests that by a combination of improved designs and of more energy efficient management, aircraft can be 25-30% more energy efficient by the mid 1990's (DSIR, 1978).

In summary, the two most important forward planning activities which recommend themselves from this research are transport energy conservation and early demonstration of all apparently viable renewable transport energy forms of local or national importance. With conservation there appear to be important implications for human well-being in relieving the majority of citizens, the low-income group, of the

burden of expensive motorised transport as a sole means of convenient access to the goods and services of a subsistence life-style, and, in respect of alternative and renewable transport energy forms, it must be recalled that amongst the host of commentators reporting on global oil supply, those who predict a doubling of prices in real terms by the early 1990's are in a big majority. Since the lead-time for the development of any significant alternative, say alcohol fuels, is at least ten, if not twenty years, it is prudent for the Papua New Guinean Government to promote, and if need be, to subsidize, the early evaluation of all apparently feasible alternative renewable transport energy sources.

APPENDIX 2 AN ESTIMATION OF THE ENERGY CONSUMED BY TRANSPORT OUT OF LAE ALONG THE HIGHLANDS HIGHWAY

Table A\* : Number of vehicles per week going from Lae to -

Vehicle type	Bulolo Turnoff	Bulolo T/o Nadzab	Nadzab	Markham Valley	Bulolo/Wau	Eastern Highlands	Beyond Eastern Highlands
Car	785	75	1030	212	88	43	19
Utility	865	79	564	341	238	154	74
PMV	463	93	248	389	221	66	24
L. Truck	322	22	170	104	130	82	77
H. Truck	60	5	39	46	87	165	231
Other**	56	2	28	14	10	2	1
Distance from Lae (Km)	7	26	33	160	146	213	213***

\* Taken from the Department of Transport Highlands Highway Su-vey conducted in December 1977.

\*\* Predominantly buses.

\*\*\* The interest is in the distance travelled by vehicles on petrol and diesel purchases made in Lae. Travel further than 213Kms would use stocks bought en route.

Table B : Fuel consumption for travel on Highlands Highway (Litres/week)

Vehicle type	Bulolo Turnoff	Bulolo T/o Nadzab	Nadzab	Markham Valley	Bulolo/Wau	Eastern Highlands	Beyond Eastern Highlands	Total
<b>A. Petrol</b>								
Car	617	219	3819	3811	1443	1029	444	11382
Utility	680	231	2091	6130	3904	3686	1771	18493
PMV	611	456	1544	11743	6088	2652	964	24058
<b>B. Diesel</b>								
L. Truck	704	179	753	5200	5931	5458	5093	24318
H. Truck	336	93	919	5257	9073	25104	35002	75784
Other	220	29	519	1258	820	239	120	3205

Table A & B. For the vehicle types listed, Category A assumes petrol use and Category B, diesel use. However some trucks use petrol and some utilities and PMV's use diesel. The assumption made of energy form used serve merely to estimate energy use.

\*Fuel consumption rates used are 8.9Km/L for car and utility; 5.3Km/L for PMV; 3.2Km/L for L. Truck; 1.4Km/L for H. Truck and 1.8Km/L for bus.

From Table B a total of 53,933 litres of petrol and 103,307 litres of diesel fuel were used in trips out of Lae which equals  $18.5 \times 10^5$  MJ per week respectively. Including the round trip between Lae and Nadzab the energy consumed in transportation out of Lae on fuel purchases made in Lae becomes  $3,200 \times 10^5$  MJ/annum.

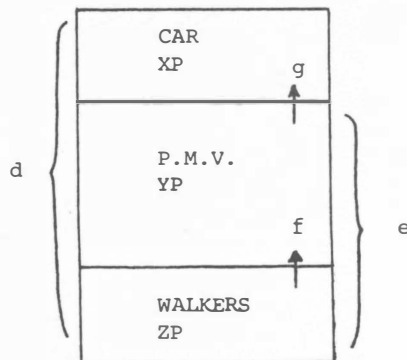
APPENDIX 3    MATHEMATICAL BASIS OF THE TRANSPORT ENERGY PROJECTIONS  
MODEL OF FIGURE 27

Where  $ZP$ ,  $YP$  and  $XP$  are the percentages of Lae's population who walk, use public motor vehicles and private cars respectively as their main transport mode and  $d$  equals the percentage natural growth rate of the population and  $e$  the percentage increase in the population due to migration, then, with  $f$  and  $g$  assigned the percentage of pedestrians and public motor vehicle travellers respectively, who transfer to the next modal level, we have, for year  $t$  :

$$1. \quad ZP_t = ZP_{t-1} + dZP_{t-1} + e\left(\frac{Z}{Z+Y}\right)P_{t-1} - fZP_{t-1}$$

$$2. \quad YP_t = YP_{t-1} + dYP_{t-1} + e\left(\frac{Y}{Z+Y}\right)P_{t-1} + fZP_{t-1} - gYP_{t-1}$$

$$3. \quad XP_t = XP_{t-1} + dXP_{t-1} + gYP_{t-1}$$





APPENDIX 4 ENERGY CONVERSION FACTORS USED IN THE  
PAPUA NEW GUINEA HUMAN ECOLOGY STUDY

	Kg/gall	Kg/l	MJ/Kg	MJ/l	MJ/Gal*
Petrol	3.31	0.73	47.2	34.3	156.0
Distillate	3.76	0.83	46.0	38.0	173.0
Kerosene	3.58	0.79	46.6	36.7	167.0
Aviation Turbine Fuel	3.55	0.78	46.6	36.4	165.5
Aviation gasoline	3.23	0.71	47.4	33.7	193.0
L.P.G.	2.42	0.52	50.2	26.1	119.0
Fuel Oil	4.26	0.94	43.8	41.3	188.0
Charcoal	-	-	30.0	-	-
Methanol		0.79		15.6	71.0
Ethanol		0.78		21.3	97.0
Biogas			37.6		

\*Rounded off to nearest 0.5; Calculations in tables made using litre values.

Chapter 5

Energy for Households

## Introduction

The urban household sector of energy use in a developing country is an especially important one. This is true not so much because of the absolute magnitude of energy demand, but because of the very wide divergence in consumption patterns in terms of both the amounts and kinds of energy in use between the socio-economic and ethnic groups residing in rapidly growing urban centres. In Papua New Guinea the urban population is growing at about 7.5% per annum on average (Bureau of Statistics, 1978a), or about three times the growth rate of the rural population. This rate is sustained because of rural to urban migration in addition to the natural increase in the urban population. Recent immigrants from rural areas bring with them patterns of energy and food production and consumption adapted to a subsistence life style in the traditional village environment, for while the packaged foods and petroleum fuels of the market economy have reached the rural villages, the emphasis there is still on subsistence cropping of staple root crops and firewood scavenging.

Quite naturally, then, the social behaviour, techniques and technologies enabling this subsistence life style are practiced wherever possible in urban areas by recent immigrants. However, this new environment is less able to support these activities than the old, and the result is severe disruption of the physical environment and often debilitating deterioration of the traditional social system which enabled these established patterns of life.

Apart from this most telling dilemma of economic development there is the symbolism of high-energy life styles fostered by the European and Asian professionals imported to manage economic development, the European remnants of the colonial era, and the newly emergent national elite. The patterns of personal energy use adopted by the latter classes are powerful determinants of aspirations for the future held by the majority of Papua New Guineans, and they act through the market place as a persistent force bringing changes which, in our view, are frequently opposite in direction to those desired for the fulfilment of national development objectives (NRC, 1976).

As with the other sectors of energy use, a detailed end-use analysis reveals not just the physical characteristics of energy use, but the total ecological context of energy flow in an ecosystem dominated by human-beings. This broader understanding of energy use is vital to effective energy planning, for the patterns of energy use, and hence the potential for change is inextricably a function of the patterns of use of all other materials, and in turn, of the social behaviour, beliefs, attitudes, and expectations of the influential groups in the population.

This paper reports on a study of the patterns of energy use amongst the urban population of Lae. An overview of energy use in the whole of the domestic sector is sought, as well as useful impressions of energy use within several distinct social groups defined here by their respective kinds of physical dwelling; namely, self-help urban settlement dwellings, low covenant formal dwellings, high covenant dwellings occupied by nationals, and those occupied by the so-called 'expatriates'.

This chapter is one of four here describing energy use in the urban settlement of Lae, Papua New Guinea, and relates closely to a paper on energy use in Chimbu village society (Newcombe et al, 1980). All these are papers of the Energy Policy Project of the Papua New Guinea Human Ecology Programme (PNGHEP), a programme of research initiated in 1976 and completed in 1979. The PNGHEP in Lae and its hinterland was supported by UNESCO and UNEP as part of the Man and the Biosphere Programme (Project Area 11).

### The Setting of Lae

Lae is a coastal city in the humid low land tropics (latitude 7°<sup>0</sup>, longitude 147°<sup>0</sup>) at the mouth of the Markham River, and the gateway to the rich agricultural expanse of the Markham Valley. Contact with the hinterland is maintained by the Highlands Highway system that stretches back to the Southern Highlands and Enga Provinces.

In October 1977 the population of Lae was 45,100 of which 18,200 were female and 26,900 male. Of these, 4,000 were non-citizens or expatriates. The citizen population had grown at 5% per annum since

1971, and the whole population at 3.3% during that period (Bureau of Statistics, 1978a). The total number of dwellings in October 1977 was recorded as 8751 of which 8% were occupied by expatriates.

The distribution of houses by type, location and occupancy is contained in Table 28. The high-cost houses and flats are typical of suburban Australia, especially Queensland and further North in Australia. Low-cost dwellings are largely constructed by the National Housing Commission to a set of basic designs of 30-40 metres sq. in floor area. Domestic and workers' quarters are houses of about this size, though frequently smaller, but are located in the grounds of high cost housing or at factories and workshops in and around the city. They include compounds for police workers, and other service sector staff. Self-help housing, as the name suggests, is made by owners largely at their expense, although loans of up to K750 are available for construction materials in approved settlement areas. Basic services of roads, drains, demarcated blocks, pit latrines, and water are available in most self-help areas. The distinction between these homes and make-shift or temporary homes is subtle in regard to their form, but not with regard to their location. The latter are frequently in areas not formally assigned and for which no title exists, meaning that the occupants may be moved at any time. The frequency of relocation of these often quite large structures is high, a fact readily attested by comparing aerial photographs taken only months apart.

Traditional housing refers to those houses in urban villages now surrounded by urban development. These houses are made of roughly-hewn bush materials including grass and thatched roofs, though many now have corrugated iron roofing.

### The Overview

Energy is supplied to households in Lae in five distinct, mostly commercial, forms; electricity, kerosene, LPG, direct solar radiation, and firewood. Of course, much of the work performed in households is able to be performed equally well by the somatic energy of muscles as by machines powered by extra-somatic energy - the energy slaves. However, the transition to energy slaves is now in full progress. The obvious

TABLE 28 DWELLINGS IN LAE URBAN AREA IN OCTOBER 1977

	Expatriates		Nationals		Total
	Urban	Urban	Urban Settlements/ villages		
High cost detached house	556	437	32		1025
High cost flat	114	729			843
Domestic and workers quarters		1117	97		1214
Low cost project house		2088	258		2346
Low cost project flat		340	32		372
Commercial dwelling		48			48
High cost settlement house			33		33
Low cost self-help		49	1675		1724
Makeshift/temporary house		49	967		1016
Traditional house (e.g. with thatching)			129		129
TOTAL	670	4857	3223		8750

Source: Derived from percentage breakdown of dwellings in categories compiled by Bureau of Statistics for the Urban Sample Survey of Lae, October 1977.

example in Lae is grass cutting where slashing with simply fashioned flat steel blades is slowly being replaced by motor mowers, and inside high covenant households in the private sector hand washing is giving way to machine washing of dishes. It is not merely a point of passing interest in a developing country with abundant labour and high urban unemployment, however, this analysis of energy flow is mostly confined to extra-somatic energy use.

An overview of energy use in the domestic sector is provided in Table 29. Total end-use is  $2062.20 \times 10^5$  MJ, or 10.8% of energy use in Lae when bunkers are included. This energy is distributed 48% as firewood, 22% as kerosene, 22% as electricity, 7% as LPG, and 1% as direct solar radiation. The proportion that each form of energy makes of the total used in the sector is in no way indicative of the proportion each form makes of energy use in a particular class of household. As will be seen most energy forms exhibit a highly skewed distribution between housing types.

Electricity, which during the study period was derived from hydro power, reached 3573 households at mid 1976, and the number of households supplied increased 2% during the study period. All high covenant homes, and many of the domestic workers' quarters attached or associated, are connected with electricity. Similarly all low covenant dwellings constructed in urban areas by the National Housing Commission are connected with electricity as a matter of policy. In all, an estimated 18,000 people, or 40% of the population were supplied with electricity in 1976-77, and the average level of supply was 1.9 kilowatt hours per capita per day.

The data on kerosene and LPG were obtained by reworking oil company records, and from data from wholesalers and retailers cross checked with the balance of imports, re-exports and consumption in other sectors, including non-fuel use.

Kerosene is utilized by all housing types, though rarely by expatriate families, except occasionally for their recreational use. LPG, on the other hand, is used almost exclusively by expatriate families, and data on the level and pattern of supply are readily available.

Firewood is used by every type of household, though only small amounts are consumed by high covenant households for barbecues, or

TABLE 29 ENERGY USE IN THE DOMESTIC SECTOR, LAE, 1976-77

DETAILS	ELECTRICITY		KEROSENE		L.P.G.		SOLAR	FIREWOOD		TOTAL
	kwhx10 <sup>6</sup>	MJx10 <sup>5</sup>	Litres x10 <sup>6</sup>	MJx10 <sup>5</sup>	Kgx10 <sup>3</sup>	MJx10 <sup>5</sup>	MJx10 <sup>5</sup>	Kgx10 <sup>3</sup>	MJx10 <sup>5</sup>	MJx10 <sup>5</sup>
Total input in each form	12.36	445.24	1.25	459.76	273.87	134.48	26.72	7,700	996.0	2062.2
%		22		22		7	1		48	100
Average per capita per day for population of 45,100	0.75	2.70	0.07	2.79	0.02	0.82	0.16	0.68	6.06	12.55
Population served by each energy form:										
1) Households	3,573 (act)		7,000 (est)		2,320 (est)		189(act)	5150 (est)		
2) People (est)	18,000		36,000		9,300			31,000		
Energy use for population served:										
1) Per capita per day	1.9	6.8	0.1	3.5	0.05	2.7	6.5	0.7	8.8	
2) Per household per day	9.4	34.1	0.5	18.0	0.3	15.9	38.7	4.1	53.0	



traditional earthen baking, in comparison with daily requirements for cooking in the low covenant and settlement areas. Data on firewood consumption are derived from the survey of sampled households reported here, combined with urban wide household survey data on the use of open fires or wood stoves for cooking (Bureau of Statistics, 1978b).

Solar energy is utilized directly for water heating and clothes drying. Only the water heating component is included in this analysis. In February 1978 the number of solar collectors which had been installed in Lae was surveyed. They numbered 189, and the combined collector plate area was  $778.7 \text{ m}^2$ . All but a small percentage of households solar collectors were fitted out 10 and 15 years ago. Most systems appeared to be still operational, the maintenance was generally poor and frequently trees shaded collectors for part of each day. The solar input to heating water is calculated optimistically at 50% efficiency on an average installation at Lae of  $18.8 \text{ MJ/m}^2$  (CSIRO, Division of Building Research, Australia, personal communication, 1978). By this means solar energy contributes only 1% of energy used by households in Lae.

The combined average daily per capita consumption of these forms of energy in households is 12.55 MJ compared with the average consumption of firewood alone in Chimbu villages of about 16 MJ per capita daily (Newcombe et al, 1979). The difference, of course, relates to the higher thermo-dynamic quality and efficiency and end-use of the energy forms used in urban households. The obvious fallacy of comparisons on the basis of enthalpy will be seen again in the data from sampled households.

#### Fieldwork: Arriving at an approach

The purpose of fieldwork was to ascertain the patterns of end-use in households in each broad category of physical dwelling in the urban area, and in particular to examine the use of non-commercial energy forms amongst the low income groups. Since the object of this research was to define policies to alleviate problems observed, and to stabilize the supply of energy to urban dwellers in the long term, it was necessary to understand as much as possible of the ecological

context in which energy was used, including the values, attitudes, and related behaviours which influenced the selection of energy forms for particular purposes. Ultimately, the data obtained on the domestic sector were to be combined with those from other sectoral analyses to form the basis for the construction of a number of scenarios in future energy demand and supply for Lae.

With limitations on both time and financial resources, only a sample survey of households could be envisaged. The choice, then, was between a single half hour interview of a representative sample of about 500 urban households, or a less representative, but in-depth survey of a small number of households lasting several weeks. Clearly the latter offered more accurate information, and a better understanding of the environmental and cultural context of energy use. As other means exist by which to check the representative nature of the sample, this in-depth method of data gathering was selected.

Six households were sampled from each of the major housing types. Over the two week period records were taken of the physical context of energy use within the household, as well as with respect to some aspects of the historical context of energy use by the families concerned.

There is no pretence here that these households can be regarded as 'average' in a statistical sense, but neither is it obvious from our experience of the Lae community that they are exceptional to the general pattern of life within each category of housing representing a sub-group within the population.

In order to provide some insight to the social and physical context of life in each category of housing, two 'vignettes' of each category of housing are provided:

Settlement self-help household No. 1

P and L are Chimbus who have come to Lae to settle and find work. They have been in Lae for five years residing in the house they built for themselves on land they occupied in an informal settlement between the edge of high covenant housing and the foothills of the Atzera Range. Their total household income is a minimum of K60.40 per fortnight.

During the survey they had four children of their own and three adult *wantoks* sharing their house.

The house is a rectangular wooden structure 7 m x 7.4 m wide. 0.8 m off the ground and is accessed by second-hand steel steps to a single door. It is built of all second-hand materials (see plate 5). The walls are 20% flat tin, 5% cement sheet, and 75% firewood. The first two materials are from demolition and dump sites, and the firewood is scrap from a local veneer mill. The roof is of old corrugated iron. There are three windows ranging from 0.2 m to 0.5 m, none with fly wire screens. There are numerous holes and gaps in the floor and walls. At the time of the survey a packing case 2.5 m x 1.8 m x 2.1 m was being fashioned into accommodation for two of the adult *wantok* by panelling one side with tin for the roof, boarding up the open end and leaving a door space, and lining the bottom side with boarding material. There was an additional small building over the pit latrine in the corner of the block. The block was almost square, and 415 m<sup>2</sup> in all. While the land was occupied illegally in the beginning, titles are now being issued, and hedges planted at the time of occupancy now delineate the boundary.

Very little garden was planted within the block; just two pineapple plants, and a 2m x 2m patch of sweet potato (*Ipomoea batatus*) and aibika (*Abelmoschus manihot*). The family maintained three gardens of a combined area of 42m<sup>2</sup> outside of the block in the interstices of other blocks close by. These gardens grew sweet potato only at the time of the survey. Within the main block there were two betel nut trees, and 18 banana trees (*Musa* sp.). The only food animals were several hens and a duck (as compared with the usual back yard pit in the settlements). The family also kept a dog. These animals lived off the scraps from the family meals, as well as food scavenging in the neighbourhood.

The family had no electrical appliances. The only energy conversion devices were an old car wheel utilized as a fire place, and three small 'tin lamps': fruit tins or glass jars which had a rag wick emerging from the top and submerged in kerosene at the bottom. These served as

lights for some of the time, but were left burning most nights to ward off mosquitoes. Firewood was never enough to last more than one night. On one day of the 14 surveyed brown paper was used for fuel, and on another night parts of the wall were torn off and burnt. Similarly, kerosene was bought every second day or so in one litre lots, and on three nights none could be afforded.

There was no sewerage, though assistance was available from the Council to construct pit latrines. This family did not avail themselves of this service. Excess refuse was either dumped in the latrine, or burnt in heaps. There was not much that was not either burnt, consumed by the animals, recycled (i.e. soft drink or beer bottles) or buried. Water was collected from the roof in 44 gallon drums. All of the three drums in use held mosquito larvae despite the operation of a Council mosquito prevention service in the area. Potable water was fetched from the creek in the foothills near the settlement. Within six months of the survey the Council had supplied stand-pipes within easy access of settlement blocks. Drainage was adequate, but footpaths and the surrounds of houses were a quagmire after rain.

The head of the household travelled to and from his work as a labourer in the company truck, and walked to and from the pickup point. Other members of the household commonly walked several kilometres to the shops, entertainment areas, and the major market place, although these trips were sometimes on public motor vehicles (PMVs) (modified tray trucks with a canopy or mini-buses). On rare occasions the family would hire, at considerable expense, a taxi to go to the husband's work place, or to town, viewing the exercise as a form of entertainment as much as a means of transportation.

During the previous 12 months two members of the household had returned to their village in Chimbu Province. They had travelled there by PMV at a cost of K10 each. The distance covered was about 700 kilometres.

Settlement self-help household No. 2

D and B were perhaps the most enterprising of the Chimbu people in our survey. They lived in a house which was constantly being upgraded, and in which they took much pride. D had established a small business contracting to the Council to establish and maintain drains in the settlement. In addition, he maintained full employment as a caretaker. His wife worked part-time as a cleaner at a local mission. Throughout most of the study period there were five adults and one child in residence. Family income was a minimum of K80 per fortnight.

D's house conformed with modern building standards for a timber frame house. Its foundations, which were initially made of kwila log cores from the veneer mill, were now being replaced with galvanized iron pipes set in concrete, and the logs were being burnt for cooking. The walls were of cement sheet, the roofing of new galvanized iron and the floor of polished boards. The house was being divided into two, and second-hand plywood from an office in town was being used to line the house. The four windows were  $0.8\text{m}^2$ ; three had glass louvres with fly wire and the fourth was boarded up so the house could be mosquito proof if required. Foundations were being laid for extensions which will double the size of the original house.

In addition to the main house there were two *haus kuk*; one of tin  $5.5\text{m}^2$  and the other a discarded water tank 2 m high and 3.2 m diameter. The latter was the new *haus kuk* and took pride of place (see plate). Fires were lit in the middle of the floor. Pots were placed on a platform over the fire fashioned from steel mesh. A toilet building was placed over a pit latrine in one corner of the block.

The block was roughly rectangular, and of  $400\text{m}^2$ . There were no gardens inside the block, just shade trees, with grass covering the untrampled places and a surrounding hedge. At a short distance from the house in an area under a major power line, where housing was forbidden, the family owned



Plate 4 Self-help house at the foot of the Atzera Range with extensive garden in foreground

two gardens, one 70 m<sup>2</sup> and the other 108 m<sup>2</sup>. The old garden had sweet potato and sugarcane, pineapple, bananas and aibika scattered throughout.

Services were non-existent with the exception of drains. Refuse not burnt, or fed to the family dog, was buried, or in the case of cans and non-recyclable bottles, packed into a 44 gallon drum which was supposed to be emptied at intervals by the Council. No evidence was available that refuse collection occurred with regularity. Water was collected off the roof in 44 gallon drums, and they were free from mosquito larvae.

The family owned two kerosene lamps and a radio. The lamps were kept going throughout the night to avoid the mosquito nuisance.

D frequently obtained free transport to and from work although he usually started out the 5 km distance on foot. B walked to and from work, but usually took PMV's to the market 4 km away. The unemployed people in the household only walked wherever they were going.

D was the only person in the household to travel away from Lae in the previous twelve months, having been to his village in a Chimbu Province twice, once by PMV and the other time by car with European friends. The total distance travelled was 1,500 km.

#### Low covenant housing household No. 1

Mr. and Mrs. F are in their mid-twenties. They have lived in Lae for four years and for only eight months in this class of housing. They lived with their three children who were all below school age, and with a *wantok* from Mrs. F's village. Mr. F worked for the National Housing Commission as a clerk earning K83 per fortnight. Mrs. F also works. In addition Mr. F had a share in a lawn mower, and he and his associates employ a labourer in this business. Generally, lawns were mowed for K2 each, and a lawn mower operator runs a regular route in a high covenant area. The net income from this

business was approximately K15 per week, of which K6 was paid to the boy who operates the mower. The family house was a standard housing commission design 30 m square including two bedrooms, a living room and the food preparation/bathroom area plus a front verandah. Construction is of timber and the house has a septic tank, reticulated water, drainage and good road access. The block site is 336 m<sup>2</sup>, of which 150 m<sup>2</sup> is garden. The family garden was six months old and planted with sweet potato, climbing beans, cassava, sugarcane and aibika.

Around the edges of this garden, and adjacent to the house, were two briar trees, a coconut tree, an orange tree, a paw paw tree and a mango tree. The area not planted with garden was under lawn. Scraps from the garden such as leaf matter, vines, weeds and lawn clippings were piled up in a form of compost heap and dug into the soil of new gardens. The family owned no domestic animals other than a dog which was fed entirely on household scraps.

Within the house lighting was by fluorescent tubes. Only one power point was installed. Appliances were limited to a jug, a radio/cassette and an iron. Cooking was done with a double pot stand kerosene wick stove, although the family obtained broken pallets from a transport agency in Lae for firewood, and cooked on an open fire in the backyard on week-ends, or whenever otherwise feasible. Taraka, where their house is situated, is nine miles from Lae city and transport is expensive. Mr. F had the use of the employer's vehicles during week days. The rest of the family either travel by PMV or walk to and from town. During the year the family travelled 400 km by PMV's to visit relatives in rural villages.

Low covenant housing household No. 2

Mr. and Mrs. W were in their early forties, were from Papua, and have worked in the service of national or local government agencies for more than 20 years. They have four children of whom two attend local high school and two attend primary school. Mr. W works for a local government agency and earns K50 a week with overtime.



The house is an early model Housing Commission construction, similar in layout to that occupied by Mr. and Mrs. F. The external walls are of cement sheet and the internal divisions are lined with plywood. The house has two bedrooms, a living room, a kitchen/bathroom area and a verandah which for this family was always in use. The family of Mr. and Mrs. W have lived here for four years. The family owned a jug, an iron, a radio and a washing machine.

Cooking was by kerosene, though a stock of scrap timber from an industrial area in Lae was held under the house and used for cooking at week-ends in an open fireplace next to the verandah.

The block was serviced with reticulated water and with a septic tank, some refuse was collected and some burnt on site. The block was 215 metres square in total, of which 55 metres was under garden. The remainder of the ground was covered with lawn, with occasional single plants of banana, taro and cassava at the edges of the block.

The family had the use of an employer's vehicle all of the time. During the working week Mrs. W and children used PMV's to travel to and from town and the market place.

The family had not travelled outside of Lae during the previous twelve months.

#### High covenant National housing household No. 1

Mr. and Mrs. C were in their mid-thirties and had been living in urban areas for more than 15 years. Mr. C was a graduate of a Papua New Guinea Teachers College and taught primary school for nine years. At the time of the survey he was in a senior position with the government. Mrs. C was a teacher. A nephew who lived with them worked at a supermarket. Total household income was over K9,600 per year.

Both Mr. and Mrs. C were born in coastal villages in Papua. Mr. C owned land in the village as part of his inheritance and within five years the family plans to retire to the village to engage in business activities.

The house which this family occupied was a large four bedroom house of the kind allocated to all personnel of the former Commonwealth Public Service of Australia prior to Independence. Water is provided by tank at ground level and is pumped electrically to service the house. The dwelling is sewered and drained. All services had been maintained to original standards and the surrounds were predominantly lawn with ornamental trees. The family maintained a small vegetable garden on the block, although the bulk of their vegetables came from the central market place in Lae.

The family had permanent access to a government vehicle. They did not themselves own a vehicle. Appliances in the house were those standard to all high covenant government houses, although the family did not use the stove for cooking, preferring instead to use a kerosene cooker in order to save money. Similarly, ceiling fans and many lights were not used. Despite these economies the monthly electricity account was between K35-40 and was regarded as a considerable financial burden. The family had lived in the house for three years and it was the first house in which they had had a hot water system, stove and ceiling fans. They had had the use of a refrigerator for six years, a radio for seven years and a tape recorder for three years.

During the previous twelve months the family travelled to the husband's village, a total of 200 km by PMV.

High covenant National housing household No. 2

Mr. and Mrs. K were in their late twenties and had had long experience of life in urban Papua New Guinea. Mr. K was a senior public servant with a National Government Department and Mrs. K was a graduate of an Australian University. Their combined household income was in excess of K12,000 per annum.

The family did not have strong ties with traditional village communities, and had adopted a standard of living similar in many ways to that followed by middle income

expatriates in the government service. Mr. and Mrs. K shared no aspirations to return to the village to live at some later stage.

There were no significant differences between either the house or environs of this family and that of the expatriate family described as Mr. and Mrs. A. Indeed their expenditure was greater for electricity and only marginally less for vehicles than this expatriate family. Mrs. K owned a new 1.3 litre sedan car, which constitutes their sole mode of transport around Lae for employment and recreation.

The couple had lived in high covenant housing, in one case life long, and in the other for 15 years. Both people had had experience of the full range of modern electrical household appliances throughout that period.

During the past twelve months Mr. and Mrs. K had visited Australia once and have travelled to Port Moresby twice.

#### High covenant expatriate housing household No. 1

Mr. and Mrs. A were in their late thirties and had lived in Papua New Guinea for more than ten years, coming originally from Europe and Australia. They had children who were attending primary school in Lae. Mr. A worked as an engineer and Mrs. A as a teacher. The combined family income exceeded K20,000 per annum. Their house, which they leased from Mr. A's employer, was two stories with 40 metres square enclosed on the ground floor and 120 metres squared on the second. The house was timber framed raised on galvanised iron pilings. There was cement sheeting on the external walls and particle board on the internal walls. The roof was of steel sheeting with a particle board ceiling. The house had many windows and was screened against insects. All construction materials were imported.

The block site is 840 m<sup>2</sup>, of which 650 m<sup>2</sup> was lawn with ornamental shrubs and shade trees. The only food plants were four coconut and three avocado trees. A mower service called every month to trim the lawns. There were no food animals maintained, though the household had two dogs which were fed on canned pet food.

The dwelling was serviced by electricity, reticulated water, sewerage and drainage, and refuse was collected regularly. The family house had 23 electrical appliances, 22 light fittings, a gas stove and oven, plus electrical cooking appliances and wood fuel barbecue outdoors. The family had utilised most of these common electrical appliances for between 9-16 years although one third of the appliances had been purchased during the past four years. The combined power rating of these household appliances, other than lights was 7.5 kW. The family also owned a petrol-powered lawn mower.

Transportation was exclusively by car. Mr. A had the use of an employer's vehicle as a condition of his employment and the family owned a 1.3 litre sedan for use outside of work hours and by Mrs. A during the week.

The energy forms used by the household directly include electricity, LPG, firewood and petrol.

During the previous twelve months the family travelled 40,000 km by air, about 1,000 km by train, 600 km by boat and 5,000 km by car, all as part of their recreational leave.

#### High covenant expatriate housing household No. 2

Mr. and Mrs. B were in their late twenties. Mr. B was a company director and Mrs. B worked as a secretarial assistant for another firm. Both are Australian, having arrived in Papua New Guinea two years ago with intentions of staying no more than five years. The combined family income exceeds K30,000 per annum. Their house was provided by the company. It was a two-storey concrete block house with large glass panels and a steel panel roof. The first floor was of timber boarding and the inner walls were of timber panelling and cement sheeting.

The house was fully air-conditioned though ceiling fans were also installed and all doors and windows were screened from insects.

The block size is 1440 m<sup>2</sup>, of which 1188 m<sup>2</sup> was under lawn, with occasional trees of no food value. There was a 36 m<sup>2</sup> swimming pool and a barbecue area. There was no food garden

and no food animals. The household maintained two dogs and three turtles.

The dwelling was serviced by electricity, sewerage, drainage and refuse collection, and borders a council maintained road. Water was caught from the roof in two 2000 gallon tanks and pumped on demand into the house.

There were 40 electrical appliances in the house, and 36 separate light fittings. The total combined power rate of the electrical appliances in regular use was 17.25 kW. Mr. and Mrs. B operated two sedan cars, one of which was owned by the company. They also owned a 135 HP cabin cruiser which was used regularly for recreation at week-ends. Energy forms used by the household included electricity, firewood, petrol and an outboard motor mix.

During their previous annual holidays the family travelled about 12,000 km by air, and 500 km by road.

SAMPLED HOUSEHOLDSMethodology

The pattern of fieldwork differed markedly between each category of household. Settlement households were visited daily throughout the 14 day period, usually just after work and prior to commencement of cooking for the evening meal, around 4.30-5.00 p.m. Low covenant housing was visited every two or three days depending on the household, and high covenant households were visited only three times during the period.

For each household, the household members and their employment were recorded, as well as the usual mode of transportation around the urban area. Movements by the head of household during the past twelve months were also recorded. On day one of the study period questions on the usual pattern of energy used were asked and these were compared with the actual data obtained at the end of the study period. A description of the total physical environment of each household was recorded during the period. This included dimensions and contents of the house and garden, energy using appliances and superstructure material. Data on sewerage, water supply, drainage, refuse collection and public access were also recorded.

The two senior representatives of the household, usually husband and wife, were asked about their experience of the energy using appliances they owned. How much of their life had they owned and utilized each kind of appliance? For all households where it was possible, daily record sheets were issued for residents to complete the time of use of any energy-using appliance, including lights. Diagrams of the circuitry in the house were made and the power rating of each appliance recorded. The duration of the daily use of each appliance was then estimated by the householder and the sheets used to record these were collected regularly by the fieldworkers. For each house rules were drawn up for estimating electricity used for heating water. Actual consumption of electricity was recorded during the period, and the previous electricity accounts were obtained to provide a cross check on the compilation of electricity use through each end-use.

LPG gas cylinders were weighed before and after the study period, and average accounts also recorded. Kerosene use in high covenant national households was available from expenditure records taken during the same period (Christie, 1980). In self-help homes kerosene was not being purchased from a fixed-price outlet even though by law all outlets were supposed to sell at prices posted by the price controller. Therefore kerosene bought by self-help householders was weighed to determine volume and price per unit volume.

Recording firewood use accurately was perhaps the most demanding task in terms of time and ingenuity. To begin with, most households did not have a stock of firewood on hand. Firewood is usually gathered daily, depending on the source. Therefore, in order to begin recording, firewood had to be supplied by the researcher. An amount not exceeding two to three days consumption was provided, and a system devised whereby the householder agreed to take wood from one specified pile of wood only. This pile was maintained by the researcher at greater than the requirements for one day. All wood gathered by the household was placed apart from this pile. Each day the weight of firewood remaining in the 'daily supply' pile was recorded, replenished by the researcher from wood brought in by the householder, and weighed again.

This system worked well, especially since any potential fouling could be readily detected, as new wood was always distinctive in some way.

Firewood was classified according to six general categories, ranging from soft wood to hard wood, and of varying moisture contents (see Appendix 5). The net calorific values assigned were undoubtedly conservative. However, the variation in heat transfer efficiency from each type of open fireplace to the cooking vessel introduces so much variation that any greater precision in estimating the net heating value of the wood was not warranted.

An incentive payment of K2 per day per household was provided to encourage compliance with the recording pattern established, this amount was not paid over until the end of the recording period. This payment was also made in respect of records being kept on daily expenditure patterns by householders as part of related research in the wider research programme being undertaken (see Christie, 1980).

The households chosen for study were not selected at random. Self-help settlement households were all Chimbu households, with other

tribal groups associated only by inter-marriage. These Chimbu families were, in fact, the urban half of a comparative study, on economic and ecological behaviour (Christie, 1980). Hence, a great deal was known about the life conditions of these people and mutual respect was established well in advance of the energy-use study. Arrangements to survey households in other categories were made several weeks in advance of the study.

#### Diverse patterns of consumption

The data obtained from the two weeks survey of energy use in sampled households are summarised in Table 30.

High covenant dwelling expatriates use three times more energy than self-help settlers, though a comparison of the actual work value of the energy utilized will reveal a proportion far in excess of this figure.

The same comparison for low covenant housing yields a four-fold difference, and 2.6-fold for high covenant dwelling nationals.

Kerosene and firewood dominate the energy usage of low covenant and settlement dwellers, and electricity was a major energy form in high covenant households. The observed pattern of energy use in each household category is described in the following:

##### i) Self-help settlement housing

Firewood was 78% of energy used in these households and apart from coincidental lighting, was used entirely for cooking. There were very few wood stoves used in settlement areas, for they cost about K200 and last only a few years under ambient conditions; the main problem being acid attack from ashes left in the firebox. Now, according to the Bureau of Statistics (1978) 96% of self-help homes utilized urban fires for cooking purposes. The location of these fires depended on the cultural group utilizing them. Most Chimbu people cook inside, except for feasts, and the first homes they built in the humid coastal urban areas have the same basic architecture as their highland homes, which were adapted to the cold nights of high altitudes, i.e. tiny windows, if any, and indoor fire-places. Half of the Chimbu households surveyed had developed a *haus kuk* which is a separate, fully



TABLE 30 ENERGY USE IN THE SAMPLE HOUSEHOLDS (MJ/CAPITA/DAY)

DETAILS	Self-help Settlement Housing	%	Low covenant Housing Commission	%	High covenant housing occupied by PNG nationals	%	High covenant housing occupied by expatriates	%
Average number of people per household	6		5		5		3.5	
<u>Energy forms</u>								
Electricity								
Appliances			0.9		1.7		8.4	
Lighting			0.5		1.1		4.2	
Cooling					0.8		3.1	
Cooking					1.1		2.1	
Hot water					7.9		11.4	
SUB TOTAL			1.4	17	12.6	93	29.2	87
Kerosene								
Cooking	0.3	19	3.5	42	0.8	6		
Lighting	2.1	3						
Firewood	8.8	78	3.4	41	0.1	1	0.1	
L.P.Gas - cooking							2.4	7
Solar - water heating							2.0	6
OVERALL TOTAL	11.2	100	8.3	100	13.5	100	33.7	100

enclosed structure just for cooking. These were variously fashioned from old water tanks, packing cases, or merely crudely built smaller versions of their main homes, made out of scrap timber or tin. If the fireplace was indoors it rested either on a sheet of tin or in an old car wheel. Usually a piece of steel-mesh is fashioned to arch over the fire as a pot stand. The local stove manufacturer claims to be involved in a profitable venture selling a cast iron version of this simple, though very inefficient stove. We did not observe the use of this appliance at any time during fieldwork.

Firewood was generally stored under houses, which were adapted to the humid coastal environment to the extent that they were elevated up to a metre off the ground. However, the traditional village practice of airing the wood above the fire to dry was not observed in Lae and frequently wood was very moist and difficult to burn.

Traditional greens and rice were cooked in pots and pans, and frequently sweet potato was baked in the ashes of the fire, a tradition that no doubt mitigates against more energy efficient means of cooking, say, with cast iron or clay stoves.

Kerosene was used for cooking in only one of the households surveyed, but all had the capacity to use it for lighting, and most did so during the study period. The average consumption by one family who cooked for more than half of the time on kerosene, was roughly double that used for lighting on a per capita basis by other householders. Kerosene was mostly burned in makeshift lamps crudely fashioned from old fruit tins clamped against a piece of rag at the top, or through the slight refinement of jars with a rag wick pulled through a slit in the lid. It is hard to determine the task considered most important for these 'tin lamps', because they were invariably attributed the function of keeping mosquitoes at bay, and for most of the time their lighting function appeared to be secondary, or coincidental. These lamps would be lit at dusk and let burn *long tulait*, that is, until around dawn. As such they were an expensive and even dangerous form of mosquito control. Even the family in the survey group with conventional wick lamps kept

these burning all night 'because of mosquitoes'. For Chimbus in traditional highland villages, internal fires smoke heavily well into the night, ensuring effective insect control.

It is worthy of note that despite the importance of kerosene as a mosquito repellent, and for lighting, no family was able to afford kerosene for use on every night during the study period. The family cooking with kerosene reverted to firewood whenever money was in short supply.

ii) Low covenant housing commission

All households sampled were supplied with electricity, though the wiring installed provided only for one power point and lights. Electricity consistently comprised 17% of total energy used in these households. Electricity consumption was further divided about two thirds to appliances and one third to lighting. Lighting was provided by 20 watt or 40 watt fluorescent tubes, though many families had fixed an incandescent lamp as an 'outside light', and this was left burning most of the night for security.

All families surveyed owned an electric jug, a radio-tape recorder (AC/DC) and an iron. One family had a washing machine, and one a refrigerator. Christie (1980), interviewing the same families in another component of this research programme, finds that most aspire to the ownership of a refrigerator as the next appliance they would acquire if money were available.

Cooking was with kerosene and firewood and in roughly equal proportions of the total energy input. Firewood, however, was used mostly at week-ends. The differences in the efficiency of end-use of kerosene and firewood were so great that the firewood used in open fires, at week-ends, by half of the families surveyed, computes to the same energy as for the kerosene used throughout the working week. When time was available, cooking on an open fire was still apparently preferred, even though the housing design does not incorporate or acknowledge this cultural preference. In 1976, 46% of the low covenant housing surveyed in the Urban Household Survey maintained open fire places (Bureau of Statistics, 1978b).

iii) High covenant nationals

National families moved into government owned high covenant housing in large numbers during the 1970's, and especially after Independence in 1976. These houses are the same as those now occupied by the majority of expatriate government employees. It is noteworthy, then, that in our sample, national occupants of high covenant housing used only 40% of the energy per capita of expatriate residents of the same environment.

An average of 93% of household energy use by this group was in the form of electricity, 6% as kerosene and 1% as firewood. There were three major differences which existed between this housing type and low covenant housing, which influence the pattern of energy use; high covenant housing generally had electric hot water systems, ceiling fans and electric cookers installed as standard equipment. Consequently, nationals occupying high covenant houses use nine times more electricity than those in low covenant dwellings and 80% of this difference can be explained by the use of these additional electric appliances.

Electricity used for lighting and for appliances was also doubled. The high use of lighting may be explained by the need to illuminate much larger areas, and by higher electricity consumption due to larger refrigerators and the use of washing machines.

One family cooked with kerosene despite having an electric stove, because it was claimed that the regular use of the stove added far more to the electricity bill than they otherwise spent on kerosene for the same amount of cooking.

Most of the families involved with this survey found their electricity bills a great financial burden, and had already implemented means of reducing electricity consumption in the household by taking out light globes or fluorescent

tubes and restricting the use of fans. They did not appreciate, however, that about 60% of the electricity costs, in their particular circumstances, were contributed by the hot water system, where even a half-way turn down of the thermostat would save more than any of the other conservation methods already practiced.

iv) High covenant households

Electricity dominates this category of household, although the forms of energy in use were much more diverse than for the other categories of households surveyed. Electricity use in these households, on a per capita basis, was two to three times greater than for high covenant national households and 20 times more than in low covenant national households. The most significant difference in electricity consumption comes with the appliance end-use category, which averages five times more electricity than high covenant national households, and ten times low covenant households. For every other category of electricity use, except hot water, the differences are in terms of multiples greater than one. There were at least four times more appliances, on average, in expatriate households than for other categories. The significantly higher power demand of washing machines, irons, refrigerators and freezers, contributes the greatest increment. Other significant contributors to the appliance demand were hair driers, coffee percolators (not included under 'cooking'), vacuum cleaners, swimming pool pumps and dehumidifiers. Within the cooking category, toasters, frypans, and vertical grillers, plus greater use of ovens, are contributors to the high consumption. In the cooling category, higher consumption is due largely to the use of air-conditioners, and to the greater use of fans.

Lighting is much increased, because of the high density of special effect, or aesthetic illumination, using less efficient incandescent globes, and to the invariably high proportion of security lighting. Security lighting is by far the most significant use of lighting in high covenant households. In

the houses sampled, the proportion that security lighting made of total lighting ranged from 14% to 77%, with a weighted average of 60%. Put another way, security lighting makes up 9% of total electricity use for the households sampled.

Electricity consumption by expatriates for water heating is 40% higher than by nationals occupying the same housing. The non-government high covenant houses occupied by expatriates have 200 to 300 litre electric water heating systems, whereas government high covenant houses may only have element type 'at-the-nozzle' heating in the bathroom, and a 10 litre hot water storage system under the sink. Half of the families surveyed had LPG cooking systems. These usually consisted of two 10 kilo cylinders operated in sequence to provide a simple back-up system of supply.

Only one family sampled utilized a solar hot water system. Since there were 189 systems in use in high covenant houses and flats, and 1868 high covenant houses and flats, these data are likely to overestimate the current significance of solar water heating in Lae. It was estimated that if the hot water supplied by solar in this household had been supplied instead from electricity, the additional electricity consumption would have constituted 45% of the cost of electricity to the family.

Occasionally, expatriate families cook outdoors with barbecues using firewood, charcoal or a manufactured barbecue fuel. The actual demand for barbecue fuel in this sector cannot be gleaned from these data, for during the study period only one family obtained and utilized firewood for a barbecue.

### The validity of the sample data

By comparing the data obtained from sample households with the known, or estimated, supply of energy to the domestic sector as a whole the representativeness of the sample data can be better appreciated.

Using weighted average statistics obtained from Tables 28 and 30, electricity, kerosene and LPG use obtained from the survey explain 85%, 88% and 91% of the total input to the domestic sector described in Table 29.

Revenue data for the domestic sector provided by the electricity commission also enable a cross-check on the consumption patterns for electricity derived from sample households. Using the existing tariff structure, the average consumption of units per type of household, total consumers, and estimated numbers of houses in each category connected, we can derive greater than 95% of the revenue collected by the Electricity Commission from domestic consumers in Lae during the 1977-78 financial year.

### Cost and benefits, supply and demand

The five domestic energy sources dealt with here, namely; electricity, firewood, kerosene, LPG and solar, clearly have different supply and demand patterns, and are associated with very different economic and environmental costs. The differing impacts must be understood before any effective forward planning of energy supply can occur.

### Firewood

The data in Tables 28 and 30 can be manipulated to show that 70% of the total demand for firewood is from the self-help households, which includes traditional housing and makeshift and temporary housing. The remaining 30% of demand is from low-covenant households, with a negligible amount by comparison, for high-covenant households.

On the few occasions that firewood was observed being sold in markets in Lae during 1978, the price for air-dried wood was 4t/kg. However, at the time most of the firewood was either scavenged from the Atzera Hills and forest adjacent to the settlements, or gathered in the industrial area, or from building sites. The

proportion of firewood derived from each source is unknown but can be estimated from data presented in the Industrial-Commercial papers of this series (Newcombe, 1978). The maximum amount of wood-offcuts available from joineries and building sites was 1800 tonnes per year, and about 60% of this was available to employees, or to the public at large. The remainder was burnt or dumped and buried at the local landfill waste disposal site. The only other source of firewood was from the South Pacific Timber Mill in one of the industrial areas. This sawmill generated 53,000 tonnes of waste in 1978; about 80% of which was burnt, creating considerable public nuisance through the fly ash dispersed in the process. Although it was not openly encouraged, village groups could fill up a PMV with offcuts for between K7 and K10, depending on the size of the vehicle. The average load can be estimated at 1.6te following sample weighings conducted by the Lae City Council for their own purposes, and no more than 5 truck loads a week are sold from the mill. Hence 450te p.a. is a generous estimate. Scrap wood is also removed from this sawmill, presumably without fear of penalty, by residents of the Bumbu settlement across the Bumbu River adjacent to the sawmill. From observations of the daily flow of wood from this source a total of 200 te/annum is a generous estimate. In all, this amounts to 1730 te p.a.

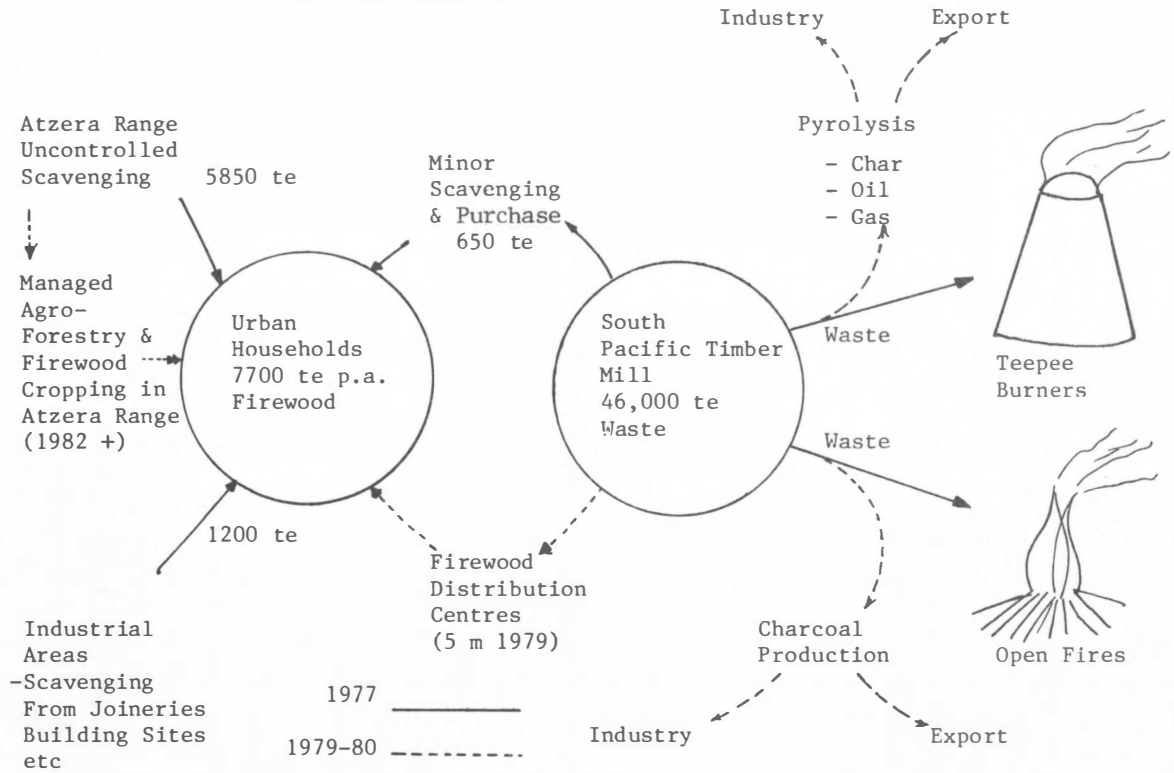
Total firewood demand is estimated at 7700 te p.a., leaving about 6000 te to be scavenged from forest areas around the settlements. If we assume an estimate of 400 te/ha of harvestable fuelwood in the secondary tropical forest around Lae, then 15 ha would be entirely cleared in 1978 just to obtain firewood. In fact the same forest is being cleared for gardening, and for structural timber for self-help and temporary housing, and the annual impact of additional burning and scavenging for these purposes probably leads to the annual depletion of 25 to 30 ha. Figure 28 is a diagrammatic representation of the firewood flow in Lae in 1977-78 and that which is being managed to apply from 1979-80 and onwards.

Of course, in practice, the impact on the forest of this scavenging is much more pervasive because, on the one hand, only in the areas immediately adjacent to the settlements is the forest cover totally removed, with canopy removal decreasing the more difficult access becomes, and on the other hand, even a 50% removal of the standing biomass can lead to severe instability and erosion in lowland tropical forests in areas of high rainfall.



Figure 28

FIREWOOD DISTRIBUTION, LAE



The legacy of this recent exploitation is obvious, though the ramifications of the changes which have taken place are still not widely appreciated. In the mid-1960's the forests adjacent to Lae were largely intact but for the extraction of high quality logs by New Guinea Industries in the late 1940's and in the 1950's. The upgrading of the Highlands Highway in the middle and late 1960's improved access to Lae from the highland areas and led to rapid rural to urban migration and a growth in the population of Lae at 17% per annum between 1966 and 1971. This growth was concentrated in low income settlements, and the quite legitimate demand for food gardens and wood grew accordingly.

In 1979, the frontal zone of the hill system called the Atzera Range was reverting to grasslands after continual gardening, and loss of fertility, and only relic specimens of the original forest canopy remained. The heavily dissected terrain is now deeply scored by erosion often down to bed-rock, and the streams draining the area become torrents of mud and debris in heavy rain. This unrestrained run-off causes tens of thousands of kina damage in identifiable costs annually to roads and suburban land. As a result of observations like these the recuperation of this hill system became a major policy objective in the Lae study (see Harris, 1978, Newcombe et al, 1980).

The Chimbu households in the survey lived further from the hills than most settlement dwellers, and their source of firewood was mostly industrial scrap. By 1978 good quality firewood from the forest could only be gathered at some distance from the settlements, and de facto ownership of the area was split between several distinct groups in the settlements and apparently effectively policed. As a result, when some of the Chimbu families had no scrap wood from industry they either burnt paper, or cardboard, or went without. There was one instance during the survey where wall boards were removed from the houses for firewood (see Plate 5).

For those with cash employment the pressure of firewood shortages leads to the tentative adoption of kerosene for cooking, with attendant costs and implications arising from an increasing dependance on imports. For those without a steady cash income more time is spent scavenging, or merely making do with much less, and accordingly their quality of life declines.



Plate 5 Fuelwood scavenged from industrial areas for use in the low income settlements at Taraka, Lae.

### Kerosene

As can be seen, kerosene is the energy form that supplants fuel wood in the low covenant and self-help households, though not always by choice. Obviously, if wood is free and available this will be the preferred energy form; but when wood is scarce, or there is no provision to burn wood in the housing allocated to families, kerosene will be used. Of course, kerosene is a modern energy form, and is a more convenient fuel to use, so higher income groups change their energy use patterns accordingly.

Kerosene was available for 15.5t/litre retail in Lae during the study period of May 1978. However, when bought at tradestores within the settlements a litre retailed for at least 20t and 25t a litre was not an uncommon price. No family surveyed had kerosene in the house every day of the study period, indicating that it was purchased only when money was not required for other purposes. Fifteen months after the study period kerosene was 20.7t/litre maximum retail price, an increase of 34%, and prices of 30t/litre were not uncommon in the settlement tradestores. The OPEC price rises of December 1979 pushed the local price of kerosene up an additional 20% over the latter prices.

We estimate that about 60% of the nation's kerosene imports are used domestically in urban and peri-urban areas. It is obvious, then, that any improvement in the supply of firewood on the one hand, and any equally convenient alternative energy form on the other, could significantly influence the present state of import dependency, and improve the standard of living of urban settlers.

### Liquefied Petroleum Gas

In May 1978, LPG was three times more expensive than kerosene, and about the same price as electricity when used for cooking in high covenant homes. In mid-1979, it was priced 25% higher than electricity. Unless there remain special reasons for its use LPG is unlikely to continue to be a significant energy form in the domestic sector in Papua New Guinea.

## Electricity

Following the conversion of the electricity supply to Lae from diesel to hydro-power in 1976, only stop-gap supplies have been generated from diesel. Electricity, nevertheless, remains amongst the most expensive sources of heat energy in the country, and its use for water heating, cooking, and soon perhaps even air-conditioning, is uncompetitive in straight financial terms with other readily available alternatives. Even so, the convenience of electricity use for these purposes, and the fact that a great many households in the private sector have their electricity accounts subsidized by their employers, maintains an inertia in the present pattern of electricity use in high covenant houses in Lae.

The price of electricity to the consumer is determined by the level of consumption, and since the present tariff structure is a promotional block tariff, the more one uses the less one pays per unit, on average. There is a paradox here in terms of both energy planning and national development goals. In the first instance the average price paid for electricity by the low covenant households in our sample was 10.2t/kWh, whereas high covenant nationals paid 6.1t/kWh, and expatriates paid 5.9t/kWh on average. The fact that low income earners pay 1.7 times more (in this sample) than upper income groups raises the question of social equity, but when it is appreciated that these low income families use electricity more efficiently and appropriately, in thermodynamic terms, the apparent distortion is further compounded. In effect the poor are being penalized for using a valuable resource efficiently. The contradiction today is that whatever the justification of the accounting approach to tariff structure, the peak demand on the grid for Lae will be met by diesel generation, at least until 1984, and the marginal cost of this electricity will far exceed the present average price per unit.

The present pricing structure also serves to encourage the use of kerosene for lighting instead of the greatly superior light source of electricity. Self-help households use four times more energy for lighting in the form of kerosene than do low covenant households in the form of electricity, but they pay only 75% as much. However, this comparison is complicated by the other end-use kerosene lamps, i.e. for mosquito control, as will be discussed later in this paper.

### Solar

Solar radiation is used directly and deliberately for water heating and clothes drying in Lae. The latter is important in the sense that a trade-off is frequently made by high covenant dwellers between occasional slow drying in the wet season and electric powered clothes driers.

The solar collectors installed in high covenant houses in Lae are, on average, older than ten years. It is only in the last two years that private consumers have perceived the economic benefits of solar water heating and new installations are again appearing. Similarly, during 1978 and 1979 the National Housing Commission was reviewing its policy on solar collector installation in new homes and large numbers of new government homes were having solar hot water systems installed.

The cost of solar hot water heating varies according to whether the systems are imported or locally produced. In Lae, at the time of the study, there was one local manufacturer. The total installed cost for a solar system with a 2.5 m<sup>2</sup> collector area, and manually controlled electric boosting, was about K550, and the payback period on investment ranged from three to five years depending on the present and imputed future level of electricity consumption for hot water heating.

### New Energy Sources and Better Management

#### Firewood

Firewood is a major energy source for 70% of the population, and as such must assume considerable importance in future planning. Despite the demand for 7700te (wwb) per year at 1978 levels there is no reason why firewood cannot be a truly renewable energy form produced as part of an integrated resource management programme for the city and its immediate hinterland.

Yields of up to 20 oven-dry tonnes/hectare per year are readily achievable in short rotation fuelwood cropping in many areas of Papua New Guinea, and yields in excess of 30 oven-dry tonnes/hectare have been recorded in the Western Highlands Province. Hence, it is conceivable that about 200 hectares of coppicing fuelwood species would

provide the city's firewood requirements at 1978 levels, and end-use efficiencies. In fact, this is just one element of the alternative strategy identified, and now under implementation.

The first is waste recycling; simply making sawmill offcuts available for firewood in the settlement areas. It is wrong that the bulk of the population should experience difficulty with the supply of firewood, and that they and the rest of the nation should suffer the severe environmental impact of the resultant deforestation, when there is at least four times the total firewood demand burnt as offcuts, and peeler log cores, within one to ten miles of the various settlements.

These offcuts or log cores, along with sawdust, shavings and bark, are burnt either in teepee burners or in open fires on the foreshore of Lae within the grounds of the city's sawmill. Nearby residents of high covenant homes have for decades complained bitterly of the fly-ash and smoke pall from this burn-off which covers their houses, gardens and washing. Consecutive local government councils have passed resolutions condemning this pollution and threatened to close the sawmill.

Now an arrangement has been made between the Council and the sawmill to donate as much of its offcuts as necessary to the Council for distribution to the settlements as firewood. The Council has established five firewood distribution centres in major self-help and low covenant settlements. These opened between April and June 1979, and firewood sales are slowly growing. Each distribution centre is staffed either by the local settlement committee or a contractor to the council. Settlement committees are admonishing the further scavenging of firewood from the adjacent hills, though until the council achieves actual administrative control of the hill system, under a management plan to be discussed here shortly, these will supply only a small proportion of total firewood demands.

Wood was sold at the distribution centres initially for 3t/kg, a price designed partly to recover the cost to the Council of transportation and construction of the centres and partly to enable firewood grown under supervision on the hills to be an economic crop. Sales in the first few months of operation at these centres did not exceed three tonnes per month per centre, a few percent of the estimated demand. Therefore, in October 1979, the price of firewood was reduced

to 1t/kg and an immediate increase of firewood sales through these centres was observed leading to decreased pressure on the hill system from firewood scavenging.

The management scheme referred to is code named the 'Atzera Project', after the Atzera Range of which the hill system is part. The Atzera Project arose out of early observations of the heavy demand for gardening and wood in the hill system and the related environmental impact. The Atzera Project is really one component of a wider management plan for the city, arising from this research, which aims to develop the city of Lae as an urban-agro-ecosystem cycling nutrients concentrated in city wastes back into the food chain through intensive subsistence-level food gardening, incorporating, as well, fuelwood cropping (Newcombe, 1979). The first design of the Atzera Project is described by Harris (1978), and the form of its implementation, with modification, is described in later reports of this UNESCO/UNEP Programme (Newcombe et al, 1980).

Briefly, fuelwood is to be produced from both dedicated cropping of a mosaic of species on land with slopes of 20° plus, where gardening is inadvisable, and in association with short-rotation gardening on lesser slopes within the hill system. The species of tree being used in the gardening areas are nitrogen-fixers (Leucena sp, Parasponia sp) believed to be compatible with vegetable production in the agro-forestry systems under trial.

Spacing trials are underway for both the dedicated firewood cropping zones, and the short-rotation agro-forestry zone. The latter trials test for combined fuelwood and vegetable yields, and overall fertility changes through the standard rotation of three years.

It is envisaged that wood harvested as part of the rotation in the agro-forestry zones will be used primarily to satisfy the firewood needs of families concerned, with any surplus being sold through the firewood distribution centres. If the average per capita demand is, say, 1kg of wood per day, at 30% moisture content (wwb) and there are six people per family, the annual requirements will be 1533 OD Kg, compared with a possible harvest per year from giant Leucena on a 40m x 40m plot of 2400 OD Kg, at 15 ODT/ha annual increment.



The firewood cropping areas would be leased for harvest under supervision by the council if, and when, the firewood was required. The chief determinant of the demand for firewood from the hill system plantations will be the availability of offcuts from the sawmill. Plans have been made to utilise all of these annually available wastes within the next five years for the production of pyrolytic fuels and charcoal to supply energy to industry in Lae, and perhaps, initially, for export (see Chapter 3).

If these schemes come to fruition firewood from the hills will be the only wood to be sold through the distribution centres, and if the Atzera management plan is successfully implemented, the vast majority of this wood will flow in strict accordance with the guidelines of the ecological management plan.

Finally, the third component of the alternative wood fuel strategy at the domestic level is more efficient combustion. According to excellent research work reported by Siwatibau (1978) for Fiji, the combustion efficiency of firewood burned in an open fire is only 31% of a wick-type kerosene burner. However, it is double that of an Indian Chula. The comparative energy efficiency for the locally produced cast-iron stoves and for open fires in Papua New Guinea is not known, though it is of vital importance to energy planning. Hence, during 1980 the Department of Minerals and Energy is funding research on the energy efficiency and social acceptance of present, and alternative wood and kerosene stoves vis-a-vis open fireplaces (for examples of alternative stoves see Gould and Joseph, 1978 and Evans, 1979) .

In addition, the use of charcoal will be examined during 1980 under a Department of Minerals and Energy Planning Programme. About six charcoal retorts will be operated through local government councils or village groups to test the acceptance of charcoal as a fuel in village and settlement areas. Initially the charcoal produced will be used to replace imported charcoal for barbecues. While half the available energy is lost in the transformation of wood to charcoal, the actual efficiency of energy use in a charcoal burner compared with an open fire is almost double (Siwatibau, 1978). In addition, the convenience of handling and transporting charcoal provides for greater economies and more flexibility from an overall energy planning perspective. Charcoal is also an important potential substitute for kerosene used for cooking.

### Kerosene

For this fuel we are faced with two complementary options; improved end-use efficiency, and direct substitution with a locally available renewable energy source.

In self-help homes the major form of lighting encountered was the 'tin lamp', a poor substitute for hurricane lamps. The latter were also in use but no pressure lamps (e.g. Coleman lamps) were observed to be in use in the settlements during the study period. Fortunately, research in Fiji at the Centre for Applied Studies and Development, University of South Pacific (Siwatibau, 1978, Table 58b) provides a useful comparison of the range of efficiencies, and hence the potential savings in kerosene in respect of the lighting appliances used in Papua New Guinea. This table is reproduced here with modifications (as Table 31).

Interpretation of this table is greatly complicated by the perception of lighting need and of main end-use by the consumer. The Coleman lamp, well-pumped, provides about 8 times higher light density for four times the fuel, when compared with a hurricane lamp. The common 'tin-lamp', however, provides 2% of the light for 20% of the energy. Theoretically, it is one-tenth as efficient. However, both 'tin-lamps' and hurricane lamps were deployed more for their value in repelling mosquitoes than for lighting.

For highlanders, in particular, the transition from a tightly sealed bush materials hut, adapted to cold nights with a fire burning slowly inside, to a loosely built airy house in the lowlands, frequently with the fire away from the sleeping areas, the fumes from incompletely burnt kerosene represent an adaptation; that is a means of repelling insects without suffering the discomfort of radiant heat from a wood fire during hot and humid nights. Here, then, the comparison of energy efficiency is not easily made. The correct comparison is with the energy cost of fly-wire, or perhaps of commercially available mosquito smoke coils, aerosol repellent and so on. It is possible that in this context the use of kerosene is competitive with these other means of insect control.

However, even when regarding kerosene lamps as lighting as well as mosquito repellent devices, the Fijian data suggest that hurricane lamps are about five times more efficient at providing lighting compared

TABLE 31 FUEL CONSUMPTION AND LIGHT INTENSITIES OF SOME COMMONLY  
USED LAMPS

Fuel	Type of Lamp	Light Intensities		Volume mls/hr	Cost of fuel/hr February, 1980 (mainports) toea*
		Foot-candles of 30cm mean	range		
Kerosene	Standing	1.5	( 0-4)	12.01	0.31
Kerosene	Hurricane	3.0	( 1.35)	12.08	0.31
Kerosene	Tilley Pressure	32	(20.70)	47.80	1.22
Benzine	Coleman Pressure	Badly pumped 20 (8-25)	Well pumped 25 (20-45)	48-57	1.26
Kerosene	Empty fish can or glass jar and wick	0.5		9.81	0.26
Electricity	60 watt globe	40			0.63**

\*1 toea = 1.45 US cents

\*\* At average price for covenant housing in our sample; 10.5t/kWhr.

Source: Adapted from Table 5.86, Siwatibau (1978).

with tin-lamps if the mosquito repellent value of each appliance can be regarded as equal.

Where lighting is clearly the only end-use of a kerosene lamp, and reasonable lighting densities are required, pressure lamps are clearly superior, and ought to be promoted.

With cooking the alternatives are clearer. The Fijian data indicate that the wick stoves commonly in use in Papua New Guinea are only 59% as efficient as Swedish primus stoves (in Papua New Guinea the same pressure stove is of German origin with the brand name 'Bat'). It is interesting though that in comparing the efficiency of these two kerosene stoves in cooking a 'Fijian meal' rather than the average for Fijian, Indian and Chinese meals, that the wick stove was only 27% as efficient; the Fijian meal is very similar to a Papua New Guinean traditional meal. The only problem encountered with pressure stoves is a fear that they will explode because of the pressure applied.

The policy options here include extensive public education on the use and advantages of particular appliances and the introduction of an import duty in proportion to appliance efficiency.

The alternative energy sources here are ethanol for lighting, and charcoal for cooking. Ethanol is planned for production at a scale of from 5-10 million litres/annum in the Markham Valley leading out from Lae by 1982. The feedstock will be sugarcane and cassava. Ethanol is an excellent clean burning lamp and stove fuel which was used widely in the 1980's and early 1900's. Germany manufactured a comprehensive range of utilitarian and artistic alcohol lamps and stoves, including coffee percolators (Wright, 1907). Similarly, the French are reported to have used methanol derived from the destructive distillation of wood for lamps in the 1850's. Spirit stoves are still sold for camping and special purposes, such as fondue cooking at the table.

These early reports suggest that ethanol was a superior fuel for lighting and that lamps had to be shielded from direct view because of their brightness. Local testing of these appliances, if they remain available, or modification of existing lamps and stoves for alcohol use is desirable, leading perhaps to local manufacture. Early reports from the major lamp manufacturer, the Coleman Company, suggest that ethanol is not an ideal fuel for combustion in their appliance. They report that the volumetric performance of ethanol is only 60% of that of kerosene and

that the lighting density is also lower. These questions will be the subject of research sponsored by the Department of Minerals and Energy with the University of Technology in Lae during 1980.

Since 60% of all kerosene use is within the housing settlements of urban areas it is conceivable that with appropriate appliances and energy efficiencies that kerosene can be substituted very largely with alcohol within a period of several years.

### Charcoal

The main substitute for kerosene for cooking is charcoal. There is no tradition of charcoal use in Papua New Guinea, although charcoal is well established in Fiji, a country within the same region, and with many similarities in cultural circumstances.

Charcoal is a smokeless fuel which is slow burning; though at very high temperatures. The fact that charcoal can introduce more control into cooking while satisfying many of the preferences which maintain the popularity of wood fires, such as smell and taste of fire and food respectively, suggests that it may be accepted as an alternative fuel.

Commercial production of charcoal began in the Southern Highlands of Papua New Guinea in 1977 using the earthen kiln method. This laborious method has not been well-received by local people. In the Department of Minerals and Energy we are improving the West Indian Retort method of charcoal production which is a much more simple, efficient and culturally compatible method (Chandler, No date).

The carbonisation cycle is at most 24 hours, compared with 10-14 days with the earthen pit method. With the West Indian retort, in the author's experience, charcoal yields of about 20% of the oven dry weight of the charge and firewood are achievable, whereas the earthen kiln method is, at best, 10% efficient in these terms.

During 1980 at least 6 demonstration projects are underway using the West Indian retort in a variety of highland, lowland and island circumstances. Suitable charcoal braziers are being copied from Thailand and Fiji to encourage village and urban settlement level charcoal cooking.

It is anticipated that charcoal can be produced and marketed for K100/te, which makes its consumption economically competitive with

kerosene on a thermal basis. Data provided by Siwatibau (1978) suggest that for Fijian meals charcoal braziers in use there are 93% as efficient as Hong Kong wick-type kerosene stoves. Whereas for cooking a common Indian meal in Fiji, Hong Kong wick-stoves are twice as efficient.

Away from mainports, however, charcoal production locally by village people, for their own use, will be markedly more economic than kerosene.

### Electricity

The supply of electricity is largely from hydro-power, and despite a growing dependency on diesel through a deficiency in long term planning, there is adequate hydro-power to provide for all conceivable requirements for the foreseeable future. This hydro-power is not cheap, however, and the development of the resource is proving to be a considerable burden on the country's total borrowing capacity and on the use of the available national skill base. Even though the average price per kW hour for high covenant houses is 8.4 US cents, the consumption is still high, and is growing in some regions at 6-8% per annum.

There have been two broad options identified here, both of which are already under implementation. One is a review of tariffs to identify the real economic distribution of costs, and especially the present marginal costs of production.

A promotional tariff assumes, amongst other things that the marginal costs of production are falling, when in Port Moresby the reverse is true. Both the new hydro-resources currently being developed and the diesel powered gas turbines installed, or planned, to provide for peaking power, generate at higher unit costs than the existing generation capacity. In effect, the higher level consumers will increasingly be subsidized while their less efficient consumption of the resource is rewarded with lower prices.

On the other hand the lower level consumers, who use the resource most efficiently, and appropriately, in thermodynamic terms, bear an increasingly disproportionate share of the costs. This form of block tariff, based on accounting rather than economic principles is a common legacy of the early rapid growth periods of electricity

supply in developed economies, and is common in developing countries, often regardless of a context which rules against its application (Turvey and McDonald, 1977). There is no consideration, either, of the question of social equity related to the greatly higher cost of electricity to small, low income users.

A tariff review has been directed by the cabinet of the national government, and accepted for funding by the Asian Development Bank.

It is obvious that a substantial saving in electricity, more particularly oil-based electricity, can result from the installation of solar hot water systems on a large scale. Proposals have been put forward by the Department of Minerals and Energy to have the building regulations amended to make mandatory the installation of solar hot water systems in all new houses in locations with favourable insolation.

#### Liquefied Petroleum Gas

LPG was as expensive as electricity for cooking purposes at the time of the study period. Following recent price increases it is 30-50% more expensive than electricity when used for heating purposes.

It is difficult to imagine much increase in the consumption of LPG in Papua New Guinea if there remains some awareness of price and thermal performance. The present market position is secured partly because of convenience and security, though both of these are questionable today. Nevertheless, while electricity brown-outs remain common in Papua New Guinea, the security offered by LPG is a significant factor, as in the preference for clean open-flame cooking by segments of the high-income population.

The alternative to LPG is biogas, although in absolute terms it is not a major energy source in urban areas. In Lae the City Council, the Department of Minerals and Energy and Appropriate Technology International, have co-operated to install a 250m<sup>3</sup> bio-conversion system. The energy production from this system will be  $19.5 \times 10^3$  MJ/day. The gas produced will be used in vehicular transportation and will be reticulated to nearby industry. Reticulation, or high pressure cylinders, for domestic use is being considered. The gross output of this system will constitute 47% of household LPG use in 1977. An upper limit on biogas production is that which could be generated from all the volatile solids from the target population

for total sewerage connections by 1981; 18,000 people. This yield would be equivalent to 2.4 times present household consumption, or the exact equivalent of total LPG use in Lae in 1977.

### Discussions and Conclusions

Two salient points emerge from this review of energy use in the domestic sector in Lae. The first is that the present efficiency of energy use, in first law terms, can be very greatly increased. Wood is squandered in open fires, and in a nearby timber mill is simply burnt as a means of disposal (see Figure 28). Where kerosene is used for lighting, efficiencies of use can be improved many times over providing there are incentives for hurricane lamps to replace tin-lamps, and for pressure lamps to replace hurricane lamps in appropriate circumstances. Where kerosene is used for cooking a two to four-fold reduction in fuel use can occur if pressure stoves replace wick stoves. Pressure stoves are already 40% cheaper but public education of their advantages is required.

As a function of building design, ignorance, and most of all, pricing, electricity is used inefficiently and both tariff and appliance efficiency changes can promote marked reductions in usage without reducing the quality of life.

LPG is the only fuel that appears to be used appropriately in thermodynamic terms but this is the most expensive energy form on the market.

The second salient feature of energy use in the domestic sector is that all energy requirements can be supplied from renewable energy sources, and furthermore, that this complete transition can greatly enhance the quality of experience of energy use, and reduce the ecological impact of present energy demands. Of course, firewood is renewable, but only to the extent that the methods of production and harvesting serve to maintain the integrity of the ecosystems from which it is drawn. This is not now the case; but under the proposed Atzera management plan a high and sustainable level of production of both fuelwood and food should be attained.

Those families who have settled on land without title, or legal right of occupancy, and who have built their own houses, and provided many of their own services, are still largely dependent on firewood. The acquisition of firewood may only be at the expense of labour which



has a negligible opportunity cost, but the cost to the community of deforestation and subsequent environmental change is considerable and, in part, directly measurable in financial terms. Many of those families with cash incomes have chosen to purchase kerosene for cooking instead of scavenging for firewood, and many perceive this change in lifestyle as beneficial. However, many also adhere to the tradition of cooking with wood and retain this facility regardless of income.

Again electricity from hydro-power is renewable, but not the diesel used to provide peak demands. Perhaps 10-20% of total domestic electricity demand can be switched to direct solar radiation for hot water heating. This exchange of energy forms within a renewable energy base is desirable for thermodynamic reasons, but the benefits are manifest in cost savings and a reduction in foreign skill and capital requirements.

Kerosene and LPG can be replaced by alcohol fuels, charcoal and biogas, given the availability of appropriate end-use systems. Special high pressure cylinders will be required for biogas, plus additional CO<sub>2</sub> scrubbing equipment, in order to replace LPG cylinders in high covenant households. The high cost of LPG already suggests that this is economically feasible (LPG was about 2t/MJ to domestic consumers, or K1 for 1Kg in January, 1980).

It is worthy of note that most of the energy management or development options identified here are under implementation or feasibility study, by the Department of Minerals and Energy, in co-operation with national or local government agencies.

Perhaps the most interesting outcome of this research is the clarification of differences known to exist between the patterns of energy use in each category of household represented in urban areas. Clearly these differences relate to differing incomes and to cultural affiliation, and there can be little doubt that the energy-intensive lifestyles of higher income groups provide a model which greatly influences the aspiration of lower income groups within the same general setting.

Appendix 5 Firewood Types: Energy Conversion Factors (MJ/Kg)

<u>Firewood</u>	<u>Softwood</u>	<u>Hardwood</u>
Green	9.5	8.9
Air-dry	17.5	13.5
Wet	7.6	7.0

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