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ENERGY MISSION REPORT
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East-West Center
Honolulu, Hawaii

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PACIFIC ENERGY PROGRAMME
MISSION REPORT

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1982

SOUTH PACIFIC BUREAU OF ECONOMIC CO-OPERATION

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ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

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Pacific Energy Programme
Mission Report

TONGA

		Page
	PREFACE	v
	EDITORIAL NOTE	vii
	MAP	ix
1.	SUMMARY AND RECOMMENDATIONS	1
2.	COUNTRY BACKGROUND	6
3.	PATTERNS OF ENERGY SUPPLY AND USE	10
3.1	Petroleum Fuels	10
3.2	Electricity	13
3.3	Biomass Fuels	17
3.4	Summary of Energy Use	18
4.	INDIGENOUS ENERGY RESOURCES: PROSPECTS FOR DEVELOPMENT	19
4.1	Indigenous Resources	19
4.2	Medium and Large Power Systems	26
4.3	Small Power Systems	30
4.4	Industry and Commerce	31
4.5	Transportation	34
4.6	Households	35
5.	PETROLEUM AND FOSSIL FUELS	39
5.1	Supply and Storage	39
5.2	Pricing and Price Control	40
5.3	Resource Development	41
6.	ELECTRICITY	42
6.1	Institutional Arrangement	42
6.2	The Power System	42
6.3	Planning Issues	43
6.4	Management Issues	44
6.5	Electricity Pricing	47
6.6	Rural Electrification	49
7.	ENERGY CONSERVATION AND MANAGEMENT	51
7.1	Opportunities for Energy Savings	51
7.2	Government Measures	53
8.	ENERGY ADMINISTRATION AND PLANNING	55
8.1	Present Arrangements	55
8.2	Issues and Options	55
	APPENDICES	59

PREFACE

This report is one of the products of a cooperative programme in which a number of organisations have worked together in helping Pacific countries assess their situation and needs in the development and management of energy resources, leading to the formulation of regional programmes for assistance in this field.

With the South Pacific Bureau of Economic Cooperation (SPEC) acting as general coordinator, the other bodies that have been involved and have contributed generously to this effort are: the Australian National University (ANU), the East-West Center (EWC), the Economic and Social Commission for Asia and the Pacific (ESCAP), the European Economic Community (EEC), the United Nations Development Programme (UNDP), and the United Nations Development Advisory Team (UNDAT).

Tonga received the mission of this Pacific Energy Programme during March/April 1982. The mission was headed by Dr. Ken Newcombe and included Tommy Scanlan, Suliana Siwatibau, and Stephen Meyers. The mission overlapped and liaised with the EEC team of Dr. Peter Shubert and Hans Dorn.

The report has been prepared by the Team Leader, Ken Newcombe, with assistance from Steve Meyers. Contributions and research and editorial assistance have been received from Suliana Siwatibau and the staff of the EWC (Resource Systems Institute and the Pacific Islands Development Program) and the ANU (Centre for Resource and Environmental Studies). The mission is grateful for the considerable achievement of the secretarial staff of CRES, ANU, and EWC in typing and correcting the report to meet tight deadlines for circulation and publication.

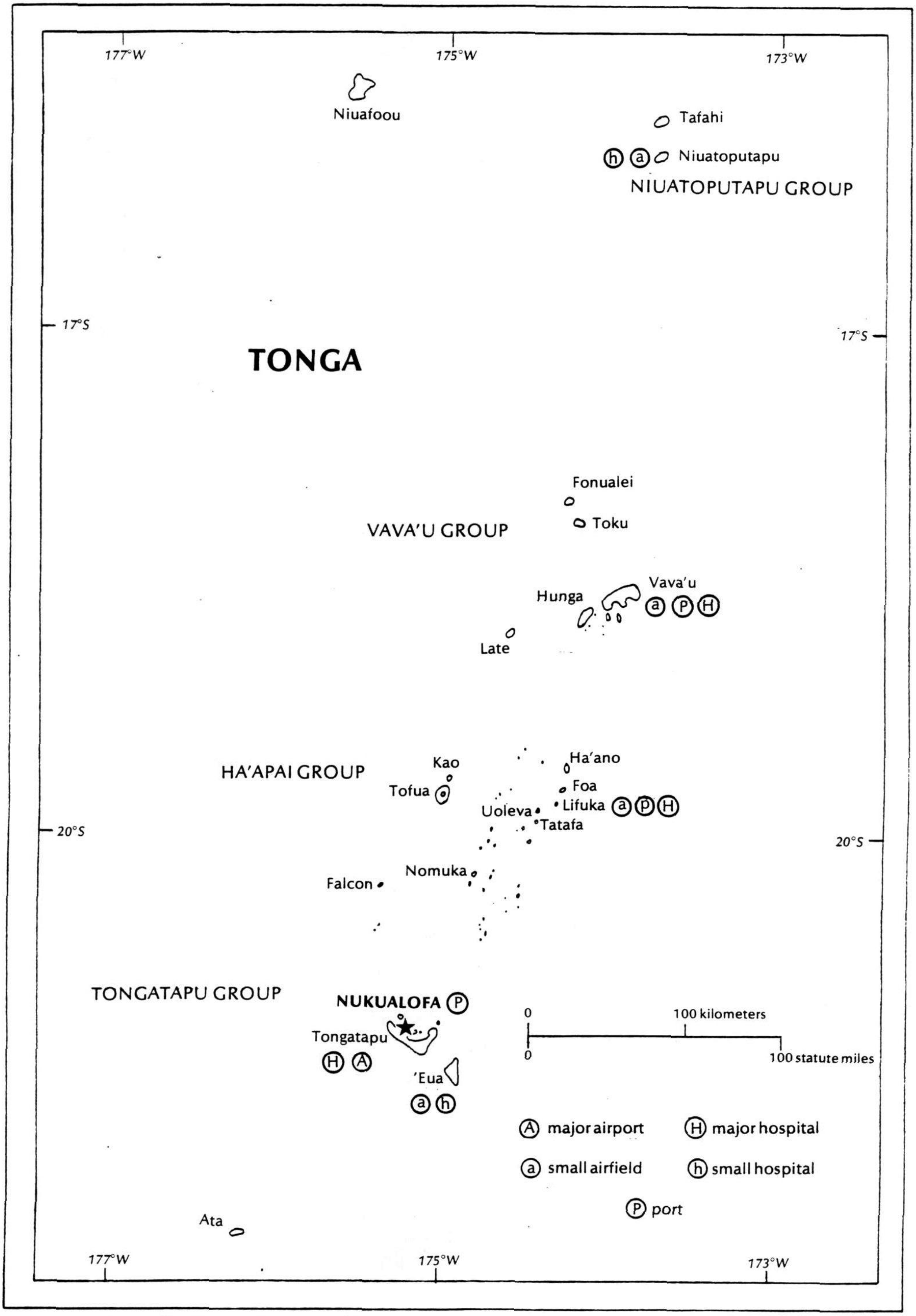
Owing to the pressing constraint of time, it has not been possible to include in this report long-term projections of energy demand or to detail the possible contribution of local energy sources and improved management in displacing imported petroleum products.

EDITORIAL NOTE

The attached report on the energy situation in this country is the result of a regional survey mission which visited 11 Pacific nations during 1982. The findings of this mission were presented in draft form to representatives of participating governments at a meeting held in Suva, Fiji in September 1982. During the process of editing the reports, it became obvious that a great deal of the information and analysis might be of general interest, but was not necessarily contained in every report. As a result, it was decided that a single outline of topical subjects should be developed and that the individual country reports should be standardised and organised around this general structure.

The result of this reorganisation has been to resequence a few sections in each report. In addition, where a country report omitted information about a particular subject, or where a subject had already been been merged with a related topic, the designation "N.A." may appear after a paragraph or section number (e.g., 4.2.10 N.A.). The purpose of the "N.A." designation is to alert the reader to the fact that there may be information of general interest on this subject available in other country reports. A set of survey reports is available in your country from the planning authorities.

By the common agreement of the sponsors, the content of the country reports is unchanged from the text agreed subsequent to the Suva meeting. No substantive changes have been made in the editing of these reports. Other than the numerical structuring of sections, the only changes have been revisions to wording and syntax designed to improve the readability of the reports.



Base map compiled from World Outline Plotting Maps, U.S. Army Map Service, 1966.

1. SUMMARY AND RECOMMENDATIONS

1.1 Summary. Tonga has an excellent opportunity to reduce its reliance on imported petroleum products by converting its two major power systems to wood fuel during the next five to seven years and by eliminating the use of diesel and Liquid Petroleum Gas (LPG) for practically all heat and steam raising during the next four years. In this way, it is possible to displace approximately 25 percent of the present level of imported fuel. The most important local energy source is the coconut crop, including senile stems, surplus husk, shell, and other residues. It is vital for the government to achieve an early and full understanding of the true availability and cost of these various coconut energy forms.

The most urgent problem facing Tonga is the continued supply of firewood for household use. More than 2,000 ha of firewood plantation must be established on Tongatapu during the next four years in order to avoid severe disruption to traditional cooking customs and rapidly declining tree cover.

The key constraints to effective energy management, and to the implementation of these major programmes, are the absence of an energy policy planning administrator and the gross underpricing of electricity. It is possible for Tonga to make major steps toward rehabilitation of the aging coconut crop and to enhance overall economic production through reform and initiative in the energy sector, providing that these most important constraints are recognised and dealt with.

1.2 Specific Recommendations and Conclusions

1.2.1 Indigenous energy resources: Prospects for development

- Coconut husk, shell, and stemwood are the key energy resources in Tonga, and their utilisation can be of direct benefit to the coconut industry. The mission recommends as a high priority a comprehensive and detailed review of the current uses and surpluses of all coconut crop residues and of the practicality and cost of delivery of such coconut palms as can be harvested annually on Tongatapu.

- Trees other than coconuts supply over 40,000 te of firewood to homes on Tongatapu. The supply of these trees is close to exhaustion. The development of fuelwood plantations integrated with "apis" and the establishment of a government fuelwood marketing authority are urgently needed reforms. About T$1.3 million* is needed to plant 2,200 ha of fuelwood over the next four years.

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*T$1 is equivalent to A$1 at the time of this writing.

- Charcoal production is the only economic means available for harvesting and storing the wood of hurricane-damaged trees before pest damage results and the economic value of the coconut timber is totally lost. Charcoal can be used for heat and steam raising, cooking, power generation, and for export in the form of charcoal briquettes.

- The mission recommends the review of a modern charcoal briquette industry for export of briquettes to Australia and New Zealand on a preferential trade basis.

- Better records of solar radiation levels in Tonga are desirable for energy planning and solar design work.

- Records of wind speed and duration should be established by installing anemometers in outer islands with communities generating significant present or future electric power demands.

Large Power Systems

- While gasification appears to be economic, sustained long-term operation of this technology has not yet been achieved in a utility context. It is not recommended that Tonga install power gasifiers until further experience is gained with this technology in the Pacific region.

- Steam power plants are proven and economic systems in the Pacific. The Tonga Electric Power Board (TEPB) should commission a detailed design and cost analysis of a 3 MW steam turbine power plant to replace diesel generation at the Popua power house as soon as possible.

- There are currently sufficient senile coconut trees available on a 62.5 yr rotation from Tongatapu to fuel a steam power station in Nuku'alofa.

Small-scale Power Supply

- Solar electricity derived from photovoltaic cells is a cheaper energy form for lighting than kerosene in outer islands. The government is urged to establish a photovoltaic cell (PVC) loan scheme to encourage rural people to use solar electricity instead of kerosene for household lighting and small appliances.

Industry and Commerce

- Boilers and ovens in Tonga can be profitably fitted with wood or charcoal gasifiers to substitute entirely for diesel. Early demonstration of this technology is proposed.

- Cooking with wood and charcoal using modern slow combustion stoves which also double as water heaters is much cheaper than

LPG or electricity. The mission urges the government to install wood stoves in the Dateline Hotel as a demonstration of this highly economic alternative.

- Institutional cooking with electricity or imported fuels in outer islands is so much more expensive than wood or charcoal that it should be prohibited and a programme devised to changeover all existing commercial cooking to solid fuels.

- Industrial-scale solar water heating is highly economic throughout Tonga. Every effort should be made by the TEPB and the Planning Office to have electric hot water systems in big institution such as boarding schools, hotels, and hospitals converted to solar or wood fuels.

- Electric drying of clothes, or of any other material or produce, should be prohibited.

Transportation

- Coconut oil is close to being an economic fuel for larger trucks, earthmoving equipment, and boats, as well as for power generation. The government is urged to conduct trials of blends of 50/50 coconut oil and diesel, first in the Popua power station engines, and then in large trucks, to better understand local difficulties to be overcome before the possible widespread use of this fuel.

Households

- Charcoal is an attractive and economic alternative to kerosene for cooking when used in Fijian and PNG charcoal stoves and ovens. Every effort should be made to promote this fuel, ensuring that proper stoves and charcoal are available simultaneously in the marketplace.

- The production and use of low-cost wood stoves of Fijian design should be demonstrated in Tonga as a cheap and convenient alternative to open fires and kerosene stoves.

- Modern slow-combustion solid fuel stoves should be installed in all new government housing as a matter of course.

- Solar hot water systems should be fitted to all government homes which use electricity heated water. A fully commercial programme to retrofit solar water heaters to private homes should be mounted through the TEPB.

1.2.2 Petroleum

- Greater competition should be encouraged among oil companies, as well as with alternative suppliers of petroleum products, in order to hold prices down as much as possible.

- Improved procedures of petroleum pricing and better training for government staff involved in price control are warranted.

- Ownership by the government of petroleum storage facilities in Tongatapu is a necessary step in the process of increasing competition in the local oil industry.

1.2.3 Electricity

Power System Planning

- The TEPB should embark on a detailed review of the power supply options reviewed by the mission in the process of developing a 10- and 20-year generation and transmission-distribution expansion plan for Tonga. This study should encompass or complement review recommended in 1.2.1 above.

- An economic planner and an engineering power systems planner are urgently needed on the staff of the TEPB.

Financial Planning and Management

- The government must review and specify the financial relationship between itself and its wholly-owned utility. The mission recommends that an entirely commercial approach to utility management be adopted, especially with regard to on-lending of power development loans and the self-financing of future expansion or replacement of plant.

- A management information system should be established within the TEPB to, among other matters, establish precisely and monitor the state of the power system and the costs of production within and between supply centres.

- The government should review the cost and benefits of the monopoly that the TEPB maintains over electrical wiring in Tonga.

Electricity Pricing

- Tariffs should reflect the full cost of production. Electricity prices are currently well below cost and significantly retard the development of more economic energy sources and energy management procedures.

- The mission recommends the introduction of a two-tiered tariff with "life-line" block initially with 50 kWH/months at 40 cents/kWh. A higher marginal price should apply on Vava'u and Ha'apai reflecting the considerably greater expense of supply in those centres.

- The mission strongly recommends against the use of electricity pricing as a means of protecting the manufacturing sector or a specific activity. Particular care should be taken to avoid heavy subsidies to commercial-industrial consumers in outer island supply centres.

1.2.4 Energy conservation and management

- The TEPB is encouraged to restrict the use of inefficient lighting and to advise consumers of opportunities to save electricity through improved appliance management. The TEPB should seek to import only the most efficient and durable electrical appliances for sale through its outlets.

- Building codes are in need of extensive revision to reduce the energy cost of owning and operating houses, factories, and commercial buildings.

- The mission recommends to the government the following measures to improve energy management and to encourage the use of more economic local energy forms:

  - Banning new installations of electric cooking, water heating, and drying (except fans) in the islands other than Tongatapu.

  - Replacing any failed electric water heater and cooker with solar and/or wood fueled appliances throughout the TEPB supply areas.

  - Drawing up strict guidelines for the use of air conditioning in the government sector, and reviewing all existing uses of air conditioning.

  - Establishing building standards for air conditioned buildings, as well as circumstances in which air conditioning will be permitted for the private sector.

- A heavy import duty should be imposed on all sedan vehicles over 2,000 cc and a sliding scale of duty adopted to favour smaller, more energy efficient private vehicles.

1.2.5 Energy administration and planning

- The TEPB should not be burdened with responsibility for alternative energy development and general energy policy planning.

- A clear statement of the goals and objectives of the TEPB should be formulated to provide guidance for the management of the board.

- An energy planning unit of at least two professional staff members is essential for any reform in the energy sector or even to take advantage of the regional energy funding now available.

2. COUNTRY BACKGROUND

2.1 Land. Tonga consists of three main island groups and many smaller islands located in the central South Pacific east of Fiji and south of Samoa. From north to south, the islands extend 560 km. Total land area is about 670 square km, with Tongatapu, the largest island, accounting for nearly 40 percent of this (Fourth Five-Year Development Plan 1980-1985). Most of the islands are of raised coral, with an overlying soil developed from volcanic ash. The land is generally fertile and suitable for cultivation. With some exceptions, it is either flat or gently undulating. Over one-half of the total land area is planted with coconut trees.

2.2 People. The mid-1982 population of Tonga was estimated at 98,000. About two-thirds of the people live on Tongatapu, with about 20 percent in the Nuku'alofa urban area. The Vava'u and Ha'apai groups have about 16,000 and 11,000 inhabitants, respectively, most of whom live in small villages. The present net rate of population increase, estimated to be about 1.4 percent per annum, represents a decline in the population growth rate from previous levels. This drop is attributable to a decreasing rate of natural increase (due in part to the government's family planning activities) and to substantial emigration, primarily to Australia and New Zealand. Internally, there has been steady migration to Tongatapu, particularly to Nuku'alofa and nearby villages.

2.3 Government. Since the adoption of the Constitution in 1875, Tonga has been a kingdom under a monarch whose heirs are entitled to perpetual succession to the throne. The Privy Council, composed of the Cabinet Ministers and the Governors of Ha'apao and Vava'u, assists the King and is the highest executive authority. Ministers are appointed by and serve at the discretion of the King. The Legislative Assembly consists of cabinet members, seven elected representatives of the hereditary nobles, and seven elected representatives of the people. Total government expenditure has risen from T$9.2 million in financial year (FY) 1975/76 to T$30.3 million in FY 1979/80 (about T$320 per capita). Nearly all development expenditure (T$19.8 million in FY 1979/80) is funded by foreign sources (Fourth Five-Year Development Plan).

2.4 Economy. Agricultural production is the predominant activity in the Tongan economy. Agricultural and agro-based products account for around 90 percent of total export earnings, and it is estimated that 70 percent of the population depend primarily upon agriculture for their livelihood. Most of the land is divided into small holdings, typically of 3.3 ha. The coconut provides a subsistance insurance to large numbers of people. Coconut products (copra, coconut oil, and dessicated coconut) overshadow all other export items, accounting for 70 percent of total export earnings. After copra, the most important export crops are root crops, bananas, and vanilla beans.

2.5 Relevant economic conditions. Economic output has increased due in part to the opening of the coconut oil mill and expansion of other manufacturing. Overall, the Gross Domestic Product (GDP) grew at an average annual rate of 12.7 percent from 1974 to 1979, although only 4.5 percent in real terms. Per capita real GDP grew at an average rate of 2.4 percent per annum. While the local economy has grown, Tonga has become increasingly dependent upon imports to satisfy the local demand for goods, and the ratio of imports to exports has risen from about 2 to 1 in 1970 to 5 to 1 in 1981 (see Table 2.1). As a result, Tonga's negative balance of visible trade has increased almost six-fold since 1973.

Table 2.1
Selected Indicators
(million T$, unless indicated)

	1976	1977	1978	1979	1980	1981
Gross Domestic Product	21.5	26.7	31.0	34.6	38.2	..
Exports (f.o.b.)	3.2	6.4	5.1	6.8	7.2	6.6
Imports (c.i.f.)	11.7	17.7	22.3	26.2	30.1	35.0
Balance of trade	- 8.4	-11.3	-17.2	-19.4	-23.0	-28.4
Key exports:						
Coconut products	2.1	4.8	3.8	4.8	4.9	..
(Coconut oil)	(nil)	(nil)	(nil)	(1.9)	(3.0)	(1.2)
(Copra)	(1.7)	(3.9)	(3.0)	(1.7)	(0.9)	(1.7)
Inflation rate (%)	12.6	16.6	5.8	12.2	23.3	..
Exchange rate (T$/US$)	0.73	0.92	0.90	0.91	0.91	0.99
Population ('000)	89.4	91.8	94.1	95.7	97.1	98.5

Notes:
(1) Population assumes 2% p.a. growth 1976-79, 1.5% p.a. 1979-81.
(2) GDP is at factor cost.
(3) 1981 trade data are provisional.
(4) Inflation is annual change in all-group index of consumer prices.

Sources: Source for exchange rate and population is ADB.
Fourth Five-Year Developmental Plan 1980-1985.
(Primarily Exports) SPC Statistical Bulletin No. 14 and SPC Statistical Economies 1980.

2.6 <u>The role of energy imports</u>. The share of total imports accounted for by petroleum fuels imported for domestic consumption increased by 50 percent from 1978 to 1981. (This excludes jet fuel, which is mostly sold to overseas carriers in U.S. dollars and should properly be considered an "import for reexport.")[1]

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1 Adjustments have been made to trade statistics to subtract jet fuel imports and account for apparent errors.

	1978	1979	1980	1981
Fuel imports (mn T$)	1.70	2.25	3.26	4.36
% of total imports	8	9	11	12
% of total exports	33	33	45	66

2.7 Development plans. Tonga's Fourth Five-Year Development Plan (1980-85) directs a larger share of resources toward agriculture, fisheries, and manufacturing. The highest priority in the agricultural sector is to support the production of food for local consumption. Greater productivity of coconut palms is also a major aim: a renewed replanting program, better use of land under coconut palms, and increased utilisation of coconut stems are planned. In fisheries, development objectives include expansion of artisanal fishing, with particular reference to providing additional employment in the outer island groups and to the establishment of an export-oriented deep sea tuna fishery. Manufacturing, assembly, and processing industries will be encouraged through incentives. Industries being established or already approved include toilet soap, coconut timber, fruit juice, and pulp. Potential industries awaiting detailed evaluation include coir products, cassava processing, fish processing, and a number of others. Controlled expansion of tourism is also planned. A general development objective is to increase the amount of resources directed to rural areas and island groups with lower than average incomes. A strategy of further reducing population is also planned.

3. PATTERNS OF ENERGY SUPPLY AND USE

3.1 Petroleum Fuels

3.1.1 Overview. Most petroleum fuels are shipped to Tonga by small tankers from storage tanks in Fiji by British Petroleum (BP), who carries products for itself and for Shell. (See Section 5.1 for details on petroleum fuel supply and marketing.) Internal use of imported petroleum fuels in Tonga in 1981 amounted to 12,500 kilolitres, about the same as in 1980. Almost 16 percent of this amount is used in transportation, and about 25 percent is consumed in electricity generation. In addition to imports for domestic consumption, about 3,700 kilolitres were loaded by overseas airlines moving passengers and cargo to and from Tonga.

3.1.2 Prices. Prices are controlled at the wholesale and retail level for motor spirit, diesel, and kerosene. Allowed wholesale prices as of May 1982 are shown below.

	Motor spirit	Kerosene	Diesel
		(T cents/litre)	
Tongatapu	45.22	46.93	44.91
Ha'api	49.62	52.14	49.31
Vava'u	46.51	49.03	46.20

3.1.3 Trends in demand. Sales of petroleum fuels in Tonga from 1973 through 1981 are shown in Table 3.1. Growth in demand for diesel fuel, which accounts for over one-half of total domestic consumption, has been strong since 1973, averaging 6 percent per annum. Most of this growth is due to increasing electricity demand. Sales of motor spirit, which accounts for about one-third of total domestic petroleum fuel use, grew at an average rate of 5 percent between 1973 and 1979, but have slowed since. Demand for kerosene and white benzine dropped sharply in 1981 (and probably fell in 1980 as well), primarily the result of higher prices.

Table 3.1

Demand for Petroleum Fuels

	1973	1974	1975	1976	1977	1978	1979	1980	1981
Diesel	4532	4223	4628	4901	4996	6076	6115	6636	6911
Motor spirit	3055	2869	3271	3445	3465	3823	4079	4173	4277
Kerosene	909	1046	1077	1065	915	979	932	920	721
White benzine	100*	110*	123	183	206	220	183	173	137
LPG	100*	100*	100*	125*	150*	171	150	299	264
Total ground products	8696	8348	9199	9719	9732	11269	11459	12201	12310
Avgas	109	150	127	119	26	137	310	198	168
Jet fuel	405	732	1313	1757	2202	3997	4422	4414	3840
Total all fuels	9210	9230	10639	11595	11960	15403	16191	16813	16318

Notes: (1) Data represent market sales as reported by Shell and BP, and LPG, imports as reported by a local supplier. Actual consumption in a given year may be different. An asterisk (*) denotes an estimate made in the absence of data.

(2) Jet fuel is mostly sold to foreign carriers on international flights.

3.1.4 Patterns of use. Domestic use of petroleum fuels in Tonga in 1981 is described in Table 3.2 according to the purposes for which the fuels are used. Fuel used in interisland shipping and air transport (estimated) is included, but fuel used in international transport is not.[2]

2 Jet fuel imported for sale to foreign carriers (about 3,700 kilolitres in 1981) should properly be considered as an import for re-export. Sales are made in US$ and transactions are handled outside Tonga. Although these flights are important to the local economy, the inclusion of the jet fuel in the domestic energy balance would distort the picture of local energy use.

Table 3.2

Use of Petroleum Fuel in Tonga, 1981

	Household uses	Transportation	Heat/Steam raising	Electricity generation	Other	Total
Diesel	-	102	20	121	18	261
Motor spirit	-	146	-	-	1	147
Kerosene	26	-	-	-	-	26
LPG	5	-	-	-	2	7
White benzine	5	-	-	-	-	5
Jet fuel	-	6	-	-	-	6
Avgas	-	6	-	-	-	6
TOTAL	36	260	20	121	21	458

Note: (1) Appendix 3.1.4 for derivation of the above breakdown.

3.1.5 Transportation sector. Transportation of people and goods accounts for some 57 percent of Tonga's petroleum fuel consumption. Within the sector, land transport accounts for an estimated 80 percent of total use, sea transport 16 percent, and air transport four percent. (An unknown amount of fuel used in interisland shipping is purchased in New Zealand. If it were included, the share of sea transport would be somewhat larger.) A further breakdown of energy use by transportation mode is as follows (percentages are approximate):

Land		Sea		Air	
Private light vehicles	39%	Shipping	11%	Jet/turboprop	2%
Govt. light vehicles	14%	Small boats	5%	Light planes	2%
Buses & heavy trucks	26%				

Motor spirit is the dominant fuel in the sector, accounting for 56 percent of consumption. About one-fourth of all motor spirit is used by government departments. It is also used in outboard motors for subsistence and small-scale commercial fishing as well as for sea transport *per se* (perhaps 10 percent of total motor spirit). The amount of diesel used in transportation is uncertain. Interisland shipping probably accounts for around one-third of total use, with the remainder used by buses (which are privately operated) and trucks.

3.1.6 Electricity sector. Electricity generation is the next largest consumer of petroleum fuel (diesel), accounting for 26 percent of total use. In addition to fuel consumption by the Tonga Electric Power Board, of which 90 percent occurs on Tongatapu, it is estimated that about 50 kilolitres are used in small diesel generators.

3.1.7 Household sector. Household uses account for under 10 percent of petroleum fuel consumption. Approximately two-thirds of this kerosene is used primarily for cooking and lighting. White benzine is also used for lighting. LPG is used for cooking by middle-income households.

3.1.8 Heat and steam raising. Less than five percent of total petroleum fuel is used for heat or steam-raising purposes. Main users are the hospital, Liahona High School, bakeries, and the coconut oil mill.

3.2 Electricity

3.2.1 Supply. Electric power is presently on a full-time basis on Tongatapu and Vava'u by the Tonga Electric Power Board (TEPB) and will soon be supplied in Ha'apai and 'Eua. Generation is entirely by diesel fuel. Installed capacity is 5,854 kW on Tongatapu, 450 kW on Vava'u. Some statistics on the TEPB operations for 1981 (calendar year) are shown in Table 3.3.

Table 3.3

Electricity Supply in Tonga, 1981

	Tongatapu	Vava'u
Installed capacity (kW)	5854	450
Firm capacity (kW)	4125	300
Generation (MWh)	10005	842
Fuel consumption (kl)	2822	285
Generating efficiency (%)	34	28
Capacity factor	0.23	0.21
Peak load (kW)	2100	210
Load factor	0.54	0.46

Notes: (1) Firm capacity reflects largest unit out.
(2) Capacity factor is the ratio of average load (assuming continuous operation) to installed capacity.
(3) Load factor is the ratio of average load to peak load.

3.2.2 Households connected to the grid. Approximately 5,000 of Tongatapu's 9,000 households are connected to the electricity grid. On Vava'u, approximately 25 percent of households have been connected to date. Thus, the overall saturation of public electricity supply is somewhat under 40 percent of the population. Reticulation is presently being installed on 'Eua and on Lifuka in the Ha'apai group.

3.2.3 Tariffs. The present structure for all customers is:

	Tongatapu	Vava'u
	(seniti/kWh)	
First 525 kWh	19.07	19.51
Over 525 kWh	17.29	18.25

The minimum charge on each bill is T$2.15 on Tongatapu, T$2.20 on Vava'u.

3.2.4 Trends in electricity demand. Growth in electricity demand on Tongatapu has slowed considerably. From fiscal year (FY) 1977/78 to FY 1979/80, generation grew at an average rate of 21 percent annually (see Table 3.4). In FY 1980/81, generation fell slightly. Growth in FY 1981/82 was 4.5 percent, although sales actually dropped.[3] (In the absence of Hurricane Isaac, growth would probably have been 6 to 7 percent.) Generation requirements on Vava'u have grown at an average annual rate of 16 percent since 1977, reflecting the recent addition of new customers.

Table 3.4

Electricity Demand Since 1977

	1977	1978	1979	1980	1981
Generation (MWh)	7160	9120	10390	10455	11040
Tongatapu	6660	8485	9740	9700	10135
Vava'u	500	635	650	755	905
Sales (MWh)	6120	7680	8660	8730	8808
Tongatapu	5720	7140	8070	8064	8050
Vava'u	400	540	590	666	758
Peak demand (kW)					
Tongatapu	1650	1960	...	...	2100
Vava'u	168	175	...	180	210
Active consumers	4063	4653	5069	5394	5822
Tongatapu	3748	4281	4645	4927	5307
Vava'u	315	372	424	467	515

Notes: (1) Data refer to year beginning July 1; thus 1977 refers to FY 1977/78.

(2) Consumers are the number at the end of the fiscal year, except for 1981/82 entry, which refers to Feb. 1982 for Tongatapu, Jan. 1982 for Vava'u.

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3 This may be due to problems in meter reading. For this reason, generation should be considered a more reliable signal of demand than sales.

3.2.5 Patterns of use. The TEPB does not keep track of sales by consumer type. A breakdown of Tongatapu sales for February 1982 is as follows:

	kilowatt-hours per month			
	0-11	12-49	50-525	Above 525
% of consumers	18	42	129	3105
% of sales	1	7	31	61
Average sales (kWh)	6	27	129	3105

Several features stand out: three percent of all consumers account for 61 percent of total sales; and 60 percent of all consumers use less than 50 kilowatt-hours (kWh) per month. A substantial percentage appear to use electricity for one light only. A similar sales pattern exists on Vava'u, although the proportion of consumers in the low-use group is even greater.

3.2.6 Rural and urban use. The TEPB classifies customers according to their location in "town" (Nuku'alofa) or "country." A breakdown of Tongatapu sales for February 1982 is as follows:

	Town	Country
% of consumers	51	49
% of sales	62	38
Average sales (kWh)	188	117

As can be seen, urban consumers use more electricity. This is only partially due to the presence of industry in Nuku'alofa, since average monthly sales among consumers using 525 kWh or less is also greater is town (72 kWh) than in the country (51 kWh).

3.2.7 Largest consumers. The largest electricity users and their monthly consumption are shown below:

Tongatapu	kWh*	Vava'u	kWh**
Liahona High School	44,620	Paradise Hotel	15,760
Cable and Wireless	35,366	Ngu Hospital	11,440
Coconut Oil Mill	32,130	Saineha High School	3,899
Dateline Hotel	31,208		
Vaiola Hospital	30,880		

*February 1982　　**November 1981

3.2.8 Peak demand. Demand for electricity on Tongatapu peaks sharply in the evening as households turn on lights. The daytime load is well below the evening peak, due in part to the fact that air conditioning is not used in most offices. The late-night load is about one-half the peak load.

3.3 Biomass Fuels

3.3.1 Cooking. Most rural households, as well as the majority of urban households, cook primarily with wood and coconut husk and shell over an open fire. In addition, nearly all households use wood for their Sunday umu. Due to a lack of data, total consumption of biomass fuels can only be roughly estimated. Based on a limited survey of households, discussion with women, and measured Fijian data, we estimate total consumption of biomass fuels in cooking as 37,600 tonnes (oven-dry) or 714 terajoules (see Appendix 3.3.1 for details). In addition, about 120 ODte of wood are used by schools for cooking.

3.3.2 Copra drying. Coconut husk and shell are also consumed in substantial quantities for copra drying. We were informed that about two-thirds of all husk and shell available are burned, which implies a husk and shell consumption of 2.3 tonnes per tonne of copra produced. With 1981 copra production of 11,234 te, this amounts to about 25,800 tonnes, or 307 terajoules.

3.3.3 Other. The dessicated coconut factory uses coconut husk as fuel in meat drying. We estimate annual consumption as 2,300 tonnes (oven-dry) or 41 terajoules.

3.4 Summary of Energy Use

3.4.1 Breakdown of total energy consumption. A breakdown of total energy consumption in Tonga in 1981 is shown in Table 3.5. Imported petroleum fuels account for 30 percent of the estimated total energy use of 1,514 terajoules. The domestic sector is the dominant consumer, accounting for over one-half of total energy consumption.

Table 3.5

Energy Use in Tonga, 1981

	Imported Petroleum Fuels		Inigenous	
	Direct	Indirect	Biomass	Total
	(terajoules)			
Domestic	36	44	714	794
Transportation	262	nil	nil	262
Primary industry	12	<1	299	311
Manufacturing	9	8	41	58
Services	11	67	2	80
Other	9	nil	nil	9
TOTAL	339	119	1056	1514

Notes: (1) Indirect use: Energy used in electricity generation is distributed among the sectors according to their electricity consumption.

(2) Services includes private commerce as well as government services.

4. INDIGENOUS ENERGY RESOURCES: PROSPECTS FOR DEVELOPMENT

4.1 Indigenous Resources

4.1.1 Overview. The basis of Tonga's economy is also its major indigenous energy resource: the coconut crop, including the standing biomass of coconut trees. The natural forest resource is tiny and, moreover, in danger of complete exhaustion. Solar radiation is relatively good, and there is a wind resource, though its potential has not been assessed. In the next century, the considerable energy of waves and ocean thermal gradients may become commercially available, although for the moment harvesting of these resources is regarded as solely experimental. Because of its importance, the mission has chosen to concentrate on defining further the biomass resource, particularly that arising from the coconut industry.

4.1.2 Biomass resources. Remaining natural forest cover is estimated by the Ministry of Agriculture, Forests, and Fisheries (MAFF) as only 4,000 ha, mostly on the island of 'Eua. There is no doubt that this forest is under pressure for firewood, agriculture, and rough building materials, a situation which is viewed with concern by the government. The mission estimated commercial sales on Tongatapu of some 200 te of wood harvested from forest clearing on 'Eua, a tiny amount that would not by itself constitute a threat to the forest resource. The government has agreed with the mission, and with FAO (regional) representatives, that a survey of remaining outer island forest resources is necessary, incorporating identification of the threats to their integrity as a sustainable resource.

4.1.3 Coconut energy resources. Accordingly, the mission arranged for a more detailed review (funded by SPEC) of the threat to forested areas on 'Eua, Tongatapu, and Ha'apai and of the domestic demand for forest timber for firewood. This review proceeded in August 1982. This fuelwood plantation and firewood use study indicated a domestic firewood demand on Tongatapu of 40,800 te/y of wood, 18,700 te/y of husk and shell, and 5,400 te/y of coconut fronds, which accords with the review of the mission in absolute amounts when converted to oven dry tonnes, and confirms an uncertainty that we had at the time of our fieldwork: large quantities of wood, in addition to coconut residues, are used for cooking on Tongatapu.

The implication is very serious: fuelwood is about to be exhausted on Tongatapu and unless action is taken immediately to establish plantations to meet future domestic firewood demand, considerable social disruption and environmental degradation will result. The fuelwood consultant estimates the need for 2,200 ha of plantation timber by 1985 and 2,600 by 1995, costing in the first instance T$1.32 million over the next four years at T$600/ha. The consultant and this mission concur on the need for government to enter the firewood market, guaranteeing a fair price for firewood delivered by small holders to a wholesale depot. Since most of the 2,200 ha of plantation must be established in existing "apis," we consider this government involvement absolutely vital to the scheme's success. The government is advised to begin preparation and planning immediately to establish a nursery to produce 3 million seedlings/yr of the recomended firewood species (<u>Eucalypt</u>, <u>Acacia</u>, <u>Leucena</u>) and to raise monies through aid to initiate this programme.

Whole nut harvesting applies for the supply of coconut meat to the dessicated coconut factory on Tongatapu. Up until 1982, some 8 million nuts were purchased each year, leaving about 5,000 tonnes of husk and shell at the factory after the extraction of the meat. Reject nuts are used for copra production with fairly inefficient drying consuming some of these residues; and up to 2,600 te of husk and shell were sold (separately) to householders and others in 1981 for perhaps T$2-3/tonne. Most of the remainder is used to fire the dessicated coconut driers. In the new factory, rated at 15 million nuts/year, drying will be more efficient, although precisely how much husk is required will only be known after a sustained period of operation. Regrettably, the new husk and shell fired boiler scheme is not working well. Shell amounting to about 2,200 ODte is currently sold (as above) or disposed of. Husk should amount to about 4,700 ODte p.a., of which perhaps one-half (2,400 ODte) will be free for use as a fuel elsewhere in the economy [see Appendix 4.1.3(a)].

Husk and shell should in theory be available as surplus to smallholder copra drying even now, despite the use of traditional and inefficient methods of drying. Surpluses should exist because solar drying of copra is practiced for part of the crop, either for part or all of the drying required. The difficulty in determining the true availability of coconut residues arises from inadequate understanding of the use of husk and shell for domestic cooking. Fieldwork by the mission did not reveal large surpluses of husk and shell piled up and rotting or being burned as a means of disposal. Indeed, there is a demand for the husk and shell surplus to the dessicated coconut factory requirements in the domestic sector. We conclude that most husk and shell remaining from a combination of solar and residue fired copra drying is utilised for domestic fuel at some time. (This conclusion is supported also by the findings of the SPEC fuelwood consultant.) Although the proportion of solar drying of the copra crop is not known (although by observation it is common), we would assume that 25 to 50 percent of the crop is dried by the sun or with solar assistance. By deduction, if all of the husk and shell would normally have been used for drying copra, then 25 to 50 percent of the 20,000 ODte "available" from the 1981 crop has been used domestically (35 percent is assumed), and the remainder of about 13,000 ODte for copra drying. With efficient (centralised) drying methods, some 3,560 ODte is required, leaving a theoretical surplus of about 9,400 ODte.

The husk and shell resource will be defined here as the total of the potential surplus from centralised efficient drying to replace husk and shell fired small holder kilns and the excess of that required for processing dessicated coconut. These amounts total roughly 14,000 ODte: clearly significant in the context of local energy demands.

The mission recommends an urgent review of the current use of coconut husk, shell, timber, and other coconut tree residues for fuel for both cooking and copra drying to establish more accurately the availability of husk and shell as an industrial fuel and the implications of this redirection (most expediently through expanded whole-nut harvesting) for household "firewood" supply. This review should be an extension of the wider fuelwood, firewood, timber, and general forestry development study referred to earlier.

Prior to Hurricane Isaac, the stand of coconut trees in Tonga was estimated to number 4.98 million over an area of 40,285 ha. About 45 percent of the trees were classified as senescent, senile, or overmature and thus available for some form of stem processing over the next 15 years [see Appendix 4.1.3(b)]. These trees have been classed as a sawlog resource, though MAFF has recognised a role for the timber as fuel to displace the diesel used to generate electricity. From the mission's review of the palm tree resource, it is clear that more than enough good quality timber exists under any scenario of removing unproductive specimens to meet the present demand for imported timber. The limiting factors are likely to be those of quality of the local product and reliability of supply. When viewed primarily as a source of energy rather than merely for timber, the standing biomass of coconut palms assumes much greater importance for import substitution.

Over the next 15 years, an average annual harvest of 151,000 senile trees or about 145,000 m^3 of timber is possible in principle and would yield more than double the present annual gross energy input to the economy of imported petroleum. While this quantity of energy in the form of coconut trees cannot be used to displace liquid fuels for transportation, it can displace diesel in power generation. Using proven steam-turbine power systems fueled by coconut trees, the power production potential of the proportion of the crop that can be culled in Tongatapu is the equivalent of 13.2 GWhrs per year compared with the present power production of 11 to 12 GWhrs [see Appendix 4.1.3(b)]. The MAFF has proposed a scheme of culling senile palm trees that calls for harvesting 80,000 trees per year, which is equivalent to a rotation of 62 years for the present crop. The value of the coconut tree as an energy source and the improved yields of hybrid varieties may allow shortening of the rotation. However, even this harvest (which is smaller in the short term to that possible due to the high proportion of aged trees in the present stand) would be sufficient on Tongatapu to generate 10.6 GWhrs p.a., roughly the 1981 production of electricity. Under either harvesting regime, the conversion of wood to electricity by gasification rather than via steam could as much as double their contribution, expanding the resource accordingly (see section 4.3).

In summary, it is clear that there is very much more energy available annually in the form of senile coconut tree stems than can be utilised other than in Tongatapu where the prospect of wood-fired power generation exists. The resource amounts to between 29,000 ODte and 54,000 ODte per year over all the islands of Tonga after extracting useful timber, with roughly 40 to 45 percent of this available around Tongatapu, the main centre of demand for imported fuels.

4.1.4 Other combustible residues. Coconut leaves are not considered here explicitly as a resource, although the resource can be estimated at 25-35,000 te tonnes (as received) annually on the basis of 10 fronds of 2-3 Kg each per tree in Tongatapu alone. The review of coconut residues truly available for industrial use as energy that the mission has proposed (4.1.3) should incorporate an analysis of the availability and cost of these leaf residues. There may be a depletion of soil nutrients resulting from the removal and use of leafy material as a fuel quite apart from competition with the use of fronds for roofing, packaging, and the like. However, the cost of mineral nutrient replacements will be much less than the value of these residues as a fuel replacing imported diesel. The major constraint on the utilisation of this resource is likely to be collection and storage.

4.1.5 Charcoal production. A special consideration at the time of the mission's visit to Tonga was the devastation wreaked by Hurricane Isaac on the nation's stand of coconut trees. An estimate of the extent of the damage is provided in Appendix 4.1.5(a). A total of about one-half million trees is estimated to have been damaged. FAO (1982) has indicated that less than 10,000 m^3 of good quality timber can be recovered from the fallen or damaged trees, leaving 246,000 ODte unutilised. This timber is all utilisable as fuel, although only a small proportion of it can be absorbed into the energy economy of Tonga as presently structured. The dilemma posed by the damaged trees is that they provide a breeding ground for "rhinocerus beetle." Only the partial destruction (charring) of the trees can remove the prospect of a major outbreak of the pest, contained in recent times by biological control. At the time of the mission's consultation with the government, there did not appear to be sufficient resources available to destroy even a small proportion of this pest haven. Clean-up operations are hampered greatly by there being no economic outlet for the whole of the coconut stem or for products derived from it. The energy value of the damaged stems is the equivalent of a minimum of 160 GWhrs of electrical power available to the grid, more than 12 times Tonga's present power production. This energy will be lost within 12 to 24 months since the damaged stems will have rotted beyond recovery during that period. The mission regards some form of recovery and storage of this energy desirable for both the energy economy and the future productivity of the coconut industry.

Several patterns of charcoal production have been detailed and costed by the mission in Appendix 4.1.5(b). If the charcoal industry is to bear the total cost of cleaning after a hurricane, then in the areas of most intensive damage, with 20 to 40 trees felled per "api," the production costs "free into store" (FIS) on Tongatapu are estimated at T$104/te charcoal. If charcoal production proceeds after the "apis" are cleared, whereby the trees are gathered and cut into metre lengths, and if charcoal is produced at sawmills from waste retained there rather than sent home with the log producer, the production costs are about T$80/te charcoal. These costs exclude a royalty for each tree, and do not include charcoal storage charges or a margin for the wholesaler/retailer. If charcoal is sold for T$120-$150/te, which is well competitive with fuels other than wood itself, the margin to allocate to royalties and marketing overheads is T$20-70/te or T$1.50-6.00 per coconut tree, depending on the pattern of production and the market price. For the purposes of our analysis, a bulk price of T$120/te and a retail price of T$150/te will be used for power production and domestic consumption, respectively. The use of charcoal for power generation is discussed further in section 4.3, leading to recommendations of an early trial of this method of salvaging the energy content of damaged coconut stems.

Damage to the coconut palm stand will occur many times in the future both from wind and pests. While very little of the present biomass of damaged trees can be recovered, the mission strongly recommends that work proceed, under aid funding if possible, to establish a technically and economically viable means of harvesting damaged trees as they become available. The mission proposes that a detailed feasibility study be made of the production and export of charcoal briquettes derived from unutilised coconut stems. In the past, charcoal export has failed even though the New Zealand government granted special access to the New Zealand market for the product. One reason for the failure was soft charcoal of low density, typical of coconut wood charcoal. Charcoal crumbled to the point of being unsalable, and transport costs were very high. These characteristics present no serious problem when using charcoal for power generation or local household consumption, but export is not possible unless they are changed. Soft charcoal is ideal for crushing to reconstitute into briquettes and the briquette is both hard and dense: more than four times the bulk density of lump charcoal. Packaging can be uniform and attractive, and storage and handling can be containerised and relatively cheap. The charcoal potential of the present damaged trees is 61,500 te. If the sustained cutting of senile trees outside of Tongatapu (where the use of trees for power production is more economic) is about 4,000 tonnes charcoal per year, an industry with a sustained maximum output and a high turnup factor with flexibility to sell larger quantities, if available, could produce charcoal from damaged trees before they rot and store it for more even conversion to briquettes.

4.1.6 Hydropower. N.A.

4.1.7 Geothermal. N.A.

4.1.8 Wind energy. Wind energy may be a marginal resource in Tonga, particularly due to the great variability in strength and duration. However, in order to define its role, if any, the resource must be carefully assessed. There is not sufficient information to relegate the wind resource to a low status or to assign it prominence, although there are circumstances, such as in the outer islands of Tonga, where its application in small-scale power generation or water pumping may be economic in relation to other sources of the same work. The mission therefore recommends that a modest effort be made to establish a wind energy record in an appropriate location in the outer islands, taking into consideration the devastating efforts of hurricane-force winds at unspecified intervals. UNDP regional funds may be allocated for this purpose if the government agrees.

4.1.9 Solar energy. Solar water heating, drying, and solar electricity can and do make a contribution to the energy economy of Tonga as a substitute for imported fuel by freeing locally available residues for more profitable use, or as a means of reducing the technical burden of energy management. While the range of average daily insolution value in Tonga is probably within 15 to 20 MJ/m^2, precise data on available energy and its seasonable variability are necessary for proper system design. The mission recommends that a more extensive and detailed solar record is begun. Funds will be allocated under UNDP regional energy assistance for this purpose.

4.1.10 OTEC and wave energy. N.A.

4.2 Medium and Large Power Systems

4.2.1 Overview. In the context of the Pacific, we define any power system serving a demand in excess of 5 kW up to 100 kW peak as a medium scale. Diesel generation and, when available, hydropower commonly serve that level of demand in the Pacific region. There are many technologies known, other than the above, that can provide power at this scale. It is the view of the mission that none is clearly established as technically and economically viable in the cultural and environmental conditions of the Pacific. Larger-scale power systems, upwards of 100 kW, now based on diesel power, present similar problems in conversion to a locally available fuel to those posed by smaller systems. However, there are a number of demonstrations of the commercial or technical viability of wood-fueled power systems, namely wood gasification and wood fired steam generation. In the 5 to 100 kW range, wood gasifiers displacing all or part of the diesel fuel, and coconut oil blends, initially displacing up to one-half of the diesel, present potentially viable options. Despite their high capital cost, small wood fired steam systems must also be considered since the technology is well established. These alternative fuels for medium to large power systems will be discussed in the Tongan context. A more general review of renewable energy sources and conversion technologies and of particularly promising power production systems will be made in the overview report of the mission.

4.2.2 Hydropower. N.A.

4.2.3 Combustible resources: Wood and charcoal gasification. Here coconut husk, shell, and wood is regarded as a wood resource. In Tonga, there are two major power systems: Tongatapu and Vava'u. Both power systems can be adapted to utilise wood or producer gas, though this may be achieved with some technical difficulty. The mission has made a simple analysis both of retrofitting a wood and charcoal gasification system to the existing 150 kW Lister Blackstone sets and of installing a 250 kW matched engine generator all dual fuel (diesel-producer gas) power system [Appendix 4.2.3(a)]. By these analyses, which provide the annual cost of production in the power house, given the present daily load curve and future estimates of peak demand the cost of production for a dual fuel husk/shell and diesel mode for either of the proposed systems is 16 to 17 cents/kWh, for the charcoal and diesel mode it is 20 to 21 cents/kWh, and for diesel alone 27 to 28 cents/kWh. The gasifier retrofit, which is superficially cheaper, is here burdened with the cost of annuitising diesel engines of 150 kW each, so that they may be replaced as required. However, the capital outlay is considerably lower for the retrofit option and would be the desirable means of substituting for diesel, if the performance of gasifier retrofits was guaranteed. Projects funded by the EEC in Fiji and the Solomon Islands are designed to establish the viability of retrofitted gasifier systems in circumstances where reliable production of power from the gasifier is not critical to sustain the supply. The Tongan government should await the outcome of these projects before proceeding with gasifier retrofit projects.

The mission is unable to recommend with confidence the use of gasification technology for power production where this technology is to be relied on to supply a significant proportion of the utilities' supply on a regular basis. In our view, more experience is needed in the on-line deployment of large-power gasifiers, and this should be gained in the utilities where engineering skills are comfortably available and where management is knowledgeable and enthusiastic about demonstration of this equipment. The mission has therefore decided against proposing the use of local government funds for the Vava'u gasification project analysed above. Instead, we propose the development of a cogeneration system providing process steam and power from a boiler and steam turbine at the Oil Mills of Tonga. This system is designed by EEC engineers to displace the 1982 power and fuel purchases of 492 Mah and 166 kl of diesel. It would incorporate a 3-pass fire-tub boiler with underfeed firings producing steam at 240°C and 300 psi for a 400 kW capacity turbine coupled initially with a 100 kW generator. The generator can be updated to allow supply to the grid of over 300 kW when fuel is available, and this is certainly how the mission sees the project developing. The experience of operating a small steam turbine system in Tongatapu would be an excellent demonstration of the potential for steam turbine generation displacing the whole of the diesel power system as analysed and presented below. Technical details of the proposed Oil Mill steam project are contained in the report of EEC engineering consultants to SPEC and the government of Tonga.

For the Tongatapu power station, the power demand currently met by large diesels (1,198 to 1,927 kW) can be displaced partially, or almost entirely, with a range of wood-fueled power generation equipment. The mission has analysed those options which it regards as worthy of further detailed investigation; a wood gasifier of 1 MW retrofitting the two 1,198 kW Mirrlees Blackstone diesels, and 1 MW and 3 MW wood fired steam boiler-turbine-alternator systems [Appendices 4.2.3(b) and 4.2.3(c)].

4.2.4 Gasifiers. Gasifiers offer two main advantages compared with steam systems. The first is the low capital outlay if a gasifier can be successfully adapted to the existing engines, and a much smaller demand for a fuel (husk and shell) that is not yet gathered centrally in the large quantities required. A wood gasifier requires about 7,700 te of husk and shell to product 5 to 6 GWhrs (although supplemental diesel is also required in a dual fuel operation) whereas 10,000 te husk and shell and 6,047 te logs are required by the steam power system for the same production. A maximum firm supply of 10,000 te husk and shell (as received) has been used for Tongatapu compared with theoretical surplus available from the dessicated coconut factory and copra drying of 11,800 ODte or 18,730 te (as received). Second, gasifiers are a mechanically simple technology requiring less sophisticated maintenance and engineering than steam turbines. However, gasifier retrofits of 1 MW have not, to the knowledge of the mission, been made and operated on base-load in any circumstances similar to the Popua power station; hence there is a need for caution in adopting this option in Tonga. The success of the EEC-funded Fijian gasifier retrofit to a 385 kW diesel should influence the government's attitude toward the larger gasifier retrofit in Tongatapu.

The capital outlay for a 1 MW gasifier retrofit is estimated to be T$700,000 compared with a 1 MW steam system of T$1,500,000. The mission estimates the costs of production as 7.3 cents/kWh from the gasifier and 8.7 cents/kWh from the steam system for roughly the same annual production. This is an insignificant difference in production costs when compared with the equivalent production costs for the diesel system of 18.6 cents/kWh (see Appendix 6.5.1). It is useful to bear in mind that charcoal produced from damaged trees as part of an economic programme of coconut stem recovery could be burned in both systems, although it is an excellent fuel for gasification and would enhance the reliability of a gasifier system.

4.2.5 Steam power systems. A larger steam plant with a firm capacity designed to meet 90 percent of the near-term energy demand (although in practice it might meet more) would have a minimum capacity of 3.0 MW as 2 x 1.5 MW units. Peak and energy demands likely to be experienced later in the decade could be met by installing a further 1.5 MW unit. Our estimate of the capital cost of this system is $4.25 million and of the unit cost of production, 11 cents/kWh; again, this is substantially below the present costs of the diesel power system. There is no doubt that an investment of this size would be a major burden to the government, especially in the present circumstance where it would have to be funded entirely from the government's budget or at a significant opportunity cost through an aid donor. The facts that tariffs are not currently structured so as to recover any capital charges and that the TEPB has no reserves are, in this context, also a matter of concern (see section 6.5 for discussion on tariff policy).

The annual consumption of coconut trees by a 3 MW power station is in excess of 20,000 if husk and shell are also used as fuel and would be about 34,000 without. This may be favourably compared with our estimate of the next 15 years average availability of senile trees on Tongatapu or 68,000 and the MAFF's projected sustained yield of 35,000 trees [Appendix 4.1.3(b)].

It is the view of the mission that the most satisfactory option for power supply for Tonga is to install a 3 MW steam power plant as soon as possible and to integrate fuel procurement with a major replanting programme for the coconut stand. An important advantage of this option is that a sizable proportion of any hurricane-damaged trees in the future could be burned for power production instead of felling senile trees during that period. A cash flow of up to $5/te for trees sold at $15/te to the power station represents a major boost to a replanting programme, which could become to a large measure, self-financing if the coconut timber and charcoal briquette industry are established.

If capital expenditure proves to be a serious constraint on power system expansion and if there is no confidence after further review that coconut trees can be harvested for fuel, the gasification retrofit option must be seriously pursued.

4.2.6 Coconut oil in diesel engines. N.A.

4.2.7 Wind energy. N.A.

4.2.8 Geothermal. N.A.

4.2.9 Biogas. N.A.

4.2.10 Alternative petroleum fuels. N.A.

4.3 Small Power Systems

4.3.1 Overview. There is considerable difficulty in defining the size of a power system for a village or a remote aid-post. This is due to differing perceptions of need, varying appliance efficiencies, and varying techniques for meeting a specified need with a minimum of installed capacity for any energy harvesting device. The more general issues are discussed in the overview chapter. Here are the most economic means of serving village or administrative centre lighting, communication, and small appliances will be discussed. These end-uses are now served predominantly with kerosene and benzine lamps, and/or small diesel and petrol generators.

4.3.2 Photovoltaic cells. There is no doubt as to the technical viability of photovoltaic cells (PVCs). The economics of PVC electricity vary greatly, however, depending on the cost of fueling and maintaining the alternatives. Based on our analysis of PVC household lighting kits for Fiji, we estimate the cost of equivalent lighting service daily is about 33 cents per day for PVC (Solar Electric) and 40 cents per day for kerosene lamps (supply 8 hours of light per day from two lamps/lights of 13 W fluorescent output). The mission recommends the use of EEC funds for the installation of PVC household kits in an entire village or community on an outer island. Should this prove successful, we recommend the establishment of a PVC kit loan scheme to further promote this option.

4.3.3 Wind energy. In undertaking the resource overview, the mission recommended some evaluation of the wind resource available to Tonga. Until that evaluation is complete, it is wise to be cautious about the deployment of wind power systems. Based on preliminary analysis of the economics of wind systems in the Cook Islands, the economics of small wind-electric generators in the range 1 kW to 5 kW are better than diesel and PVC systems with costs of 80 to 90 cents/kWh. Many of the assumptions used in this analysis are, however, untested, such as the life of the equipment under humid marine conditions and occasional gale-force winds, the ease and cost of maintenance, and, of course, the energy harvested from the "marginal" wind speeds (4 m/s average) that prevails in this region. The mission has proposed the expenditure of UNDP funds in the Cook Islands in support of both a demonstration 4 to 5 kW wind generator for a village community and for further development of a small, locally fashioned, wooden bladed windmill of 100 to 300 W peak. These projects should serve to demonstrate broadly the technical viability and management of wind systems in Tonga and, at the same time, lead to a more informed decision about the priority and role of wind power in Tonga.

4.3.4 Hydropower. N.A.

4.3.5 Gasifiers. N.A.

4.3.6 Coconut oil in engines. N.A.

4.4 Industry and Commerce

4.4.1 Overview. Heat and steam raising in Tongan industry is largely with diesel and with some electricity. Only the dessicated coconut factory has a husk-fired boiler for process steam production. There are, however, very few manufacturing industries requiring heat or steam. Surprisingly, electricity is used for clothes drying in the Vava'u hospital and for water heating in hospitals, hotels, and schools. Cooking is done with LPG or electricity in most large institutions and hotels. Cooking with wood or other solid fuels is exceptional. For most of the petroleum fired facilities reviewed by the mission, there are renewable energy alternatives, most of which are economically viable and technically proven.

4.4.2 Gasifiers/hot air generators. The boiler at the coconut oil mill provides an example of the costs and benefits of retrofitting with gasifier/hot air generators. The present level of operation of the boiler is about one-half of its capacity, which will be fully utilised when the mill production is doubled in the near future. Even at the current level of utilisation, a hot-air generator-gasifier retrofit has a simple payback of less than 3 months, and an implied saving beyond the first year of operation of $13/te oil produced. This saving is significant given that the present oil milling operation is little better than break-even at present market prices for coconut oil and meal (see Appendix 4.4.2). The mission has recomended that aid be sought to design and fund this installation (given the depressed state of the coconut industry following Hurricane Issac), should the Oil Mill management reject the cogeneration project proposed under EEC funding.

4.4.3 Food industries. Bakeries in Tongatapu have modern diesel-fired ovens. Although wood fueled ovens can still be made to order, the old solid-fueled system of firing is both inefficient and difficult to control in a large mechanised operation. The installation of a gasifier/hot air generator in place of the diesel burner system appears to be a practical option. The mission has discussed this option with the supplier of the ovens in Tonga (and to most of the countries in the region), and there is enthusiasm to apply and demonstrate this technology for clean controlled burning of wood fuel to displace diesel oil. A sample analysis of such an installation at a major bakery inspected in Tonga is given in Appendix 4.4.3(a). A simple payback of five months is estimated. The mission believes that this opportunity for reducing the cost of energy in manufacturing is so attractive that it has proposed the use of UNDP funds for refinement of small hot air generators of New Zealand origin, now in use in Western Samoa, for this application. Tonga can be a beneficiary of this aid.

Biogas can be produced from the effluent coconut milk at the dessicated coconut factory [see Appendix 4.4.3(b)]. The milk is an homogenous and readily managed feedstock for high rate digestion. Gas production of 0.5 litre/gm of volatile solid dry weight would yield 67.5 million litres of gas, or about 1.5 TJ, the equivalent of 40,000 litres of diesel in gross calorific value. The fuel could be simply fired into the boilers at the factory, or it could be used for transportation or power production. Currently, the effluent is a potent and obvious pollutant. The mission has arranged for ADAB, the funding agency which donated the factory, to review the production and use of biogas from this source.

4.4.4 Solar water heating. Solar and wood fueled water heating are immediately available technologies with extremely attractive economics. When compared with either LPG or electricity for water heating, the payback period on investment is one to two years in most cases. The large secular boarding school on Tongatapu and the Dateline Hotel are the biggest consumers of electrictiy on Tongatapu, and the Vava'u Hospital and Paradise Hotel are the biggest consumers on Vava'u. All of these institutions use electric water heaters. The benefits of using solar and wood water heating in terms of reducing the unusually sharp peak in electricity demand between 7 and 11 pm are considerably for power system costs and capacity expansion, quite apart from the large savings to consumers in each case.

The mission has arranged for regional aid agencies (UNDAT/ESCAP) to fund the detailed design and costing of solar water heating for rooms in the Dateline Hotel, and the wards and low temperature use in the Vava'u hospital. This project will proceed during November and December 1982.

4.4.5 Wood and charcoal stoves. Cooking with imported liquefied petroleum gas and with electricity produced with diesel is extremely expensive and unnecessary when modern solid fuel stoves are readily available. The mission recommends that the use of wood or charcoal fueled large slow combustion stoves be encouraged in the Dateline Hotel and other large hotels, restaurants, and institutions (schools and hospitals). There is no justification for the use of electricity to cook on the outer islands when large solid fuel resources exist and where their supply could form the basis of a new small holder industry. Wood is sold in the marketplace on Tongatapu for between $28 and $71/te (airdry). This is equivalent to 25 percent of the cost of electricity at the higher price and does not allow any use of heat, otherwise wasted, for hot water systems incorporated in the stoves. Well dried coconut wood can be burned in suitably designed stoves. At $15/te fresh weight, this wood when dried is less costly than the lowest price in the market, being about 10 percent of the true cost of electricity. In small combustion systems such as industrial-scale stoves, it may be important to minimise the variability of fuel quality to ensure good control of the heat rate for cooking and baking. Either dry hardwood or charcoal may be desirable fuels. Charcoal at T$150/te retail [see Appendix 4.1.5(b)] is still less than 20 percent of the cost of electricity in cooking, allowing for the relative efficiencies of heat transfer, and not crediting water heating combined with cooking. If an expanded small holder fuelwood operation is desirable, the fuelwood plantation design and costs will be available from the fuelwood demand and production review that the mission has arranged for Tonga. (This proceeded in July 1982, under SPEC/ADAB funding support.)

Institutional cookers with large ovens and hot water boilers incorporated and designed for use with charcoal are available from Australia for T$2,900 (FOB). The rated cooking capacity is 100 persons for institutional cooking or 50 persons individually.

The mission has recommended the use of UNDP funds for a demonstration of large, modern, institutional wood/charcoal stoves in Tonga, preferably in the Vava'u Hospital, where cooking and water heating is done with electricity costing more than 40 cents/kWh.

Where wood stoves can be installed for cooking, water heating can be facilitated through a built-in water boiler. However, separate wood fired water heaters are very cheap and must be considered in any location of concentrated demand such as a kitchen, laundry, and the like. (Such water heaters can be obtained for $290 FOB Australia for a wood water boiler of 951/hr capacity at 70°C without storage cylinder.) These wood or charcoal fired water heaters are cheaper than solar systems to provide kitchen, small-industrial, and laundry water at 70°C, and are quite simple to install.

4.4.6 <u>Crop drying</u>. Solar drying is obviously beneficial for small holder copra producers when climatic conditions permit this method compared to residue fired driers. However, it is remarkable that sun-drying is not used for laundry at the Vava'u hospital and perhaps other institutions. The cost of electric clothes drying is prohibitive and the method should be discontinued. If inclement weather conditions are common, a drying room should be established using waste heat from refrigeration or other systems, or solid fuel stoves and fans.

4.5 <u>Transportation</u>

4.5.1 <u>Overview</u>. N.A.

4.5.2 <u>Ethanol fuels</u>. Despite the fact that starchy root crops suitable for ethanol production are commonly produced, the costs of production on a small scale, the use of root crops as food and as an export earner, and the small size of the motor spirit market mitigate against the economic production of this alternate liquid fuel for at least the next five years.

4.5.3 Coconut oil in diesel engines. As discussed in section 4.2, coconut oil is produced in Tonga at below, or break-even with, the prevailing price FOB Tonga of T$450/tonne (41 cents/litre at 25°C). The cost of diesel oil CIF Tonga, plus wharfage charges and losses onshore and margins to the oil company, is 34.2 cents/1, 83 percent of the coconut oil price. This does not include credits for port and service taxes paid by the oil mill to export the coconut oil. Only quite small movements upward in the price of diesel (due to exchange rates or real price escalations) and reductions in the cost of producing coconut oil (such as proposed in 4.4) are needed to make the use of coconut as a diesel fuel extender in blends up to 50/50 as economic as the export of the coconut oil. In a 50/50 blend, coconut oil is assumed to perform at parity with diesel on a volumetric basis for all practical purposes. The mission recommends that limited trials be done using 50/50 blends of coconut oil and diesel in heavy trucks under the guidance of UNDP/SPEC/USP advice to establish the technical viability of this option in Tonga's climate.

4.5.4 Biogas. The use of biogas produced from coconut milk at the dessicated coconut factory for a small fleet of trucks (5 to 10) within the commodity board operation should be examined. Biogas production and gas cleaning, compression, and dispensing units of this size are being established and operated successfully by farmers in New Zealand. If quite expensive production equipment is used that is designed for low-rate digestion of heterogenous feedstocks, our estimate of production costs are 41 cents/litre of diesel equivalent which is financially attractive for the commodities board.

4.5.5 Producer gas. N.A.

4.5.6 Wind energy. N.A.

4.6 Households

4.6.1 Overview. Cooking fuels used in Tonga are LPG, kerosene, coconut husk and shell, and wood. Electricity is rarely used by other than the highest income groups. Lighting in rural areas is mostly by kerosene and benzine lamps, and in the urban areas, electricity. From the pattern of electricity consumption, it is clear that a great many households have just one or two lights and no other appliances. Ironing is done by electricity or with benzine irons. Hot water services are not common, although the higher income groups use either gas, electricity, or, recently, solar energy for water heating.

4.6.2 Patterns of energy use. Cooking covers the highest demand for energy in the domestic sector. Kerosene, LPG, and electric appliances used in this sector can be displaced with appropriate solid fuel stoves. There is much to recommend the use of charcoal in the near term for all income groups except where free wood is abundant. Charcoal stoves can be made and sold locally at a price attractive when compared with kerosene stoves, about T$15 to T$30 for one and two burner stoves of Fijian design. Charcoal stove/oven combinations of Papua New Guinean design would cost T$50 made locally. All parts of the country have coconut wood ready for harvesting, although the wood is not attractive as a fuel when used directly unless it is split right down to billets and dried for some months. Charcoal can be made from coconut palm logs in 25 to 30 cm pieces in 3 to 6 m^3 kilns, or from halved logs of the 30 to 60 cm in 200 litre drums. This last method was pioneered in Tonga and has given rise appropriately to the "Tongan Kiln" method. Coconut wood charcoal is a widely acceptable fuel which, although generally low in density, it easy to light and compatible with the Fijian stoves, water heaters, or slow combustion stoves the mission favours for households and institutions in Tonga.

4.6.3 Wood and charcoal stoves. Low-cost wood stoves have an application for low- and middle-income families, both to make more efficient and convenient use of wood and coconut derived fuels now consumed and to displace kerosene cooking. Tongan women, community groups, and the extension office of the MAFF responded enthusiastically to the concept of local demonstrations and then local construction of the more advanced Fijian stoves, which are an improvement on the SPC stoves previously demonstrated in Tonga. The USP Rural Development Centre and the government-supported Rural Development Centre run by Tongan women are both well placed to demonstrate, and to provide the initiative for, local production of the Fijian MK II/III stoves and Fijian and Papua New Guinean charcoal stoves and ovens. The mission observed that previous attempts to use charcoal domestically, in the aftermath of the collapse of the export industry, had failed because charcoal stoves and ovens were not available to consumers. Promotion of charcoal as a fuel and suitable stoves must go hand in hand.

The mission has encouraged the early demonstration in Tonga of new small modular wood stoves and charcoal stoves and ovens and has arranged funding for materials and expertise for this purpose for Tonga for an extension programme in September 1982.

Large solid fuel stoves and ovens can readily displace electric and LPG cooking in urban and small areas where these fuels are supplied. Traditional methods of baking in the earthen oven or "umu," which take place regularly for Sundays in Tonga, will not be replaced with modern ovens, although baking of bread and other foods during the week may well be acceptable in modern slow combustion stoves. Wood and coconut residues of all kinds can be burned in slow combustion stoves, although dry hardwoods and charcoal are much superior fuels. If coconut wood from all parts of the stem is to be used as a domestic fuel, larger fireboxes with higher volume flows of air of combustion will have to be adapted.

The mission believes that there is an urgent need to demonstrate good quality, slow combustion stoves in upper income government housing. We note that new government housing in many areas is now designed for the use of wood stoves and that other agencies have encouraged this facility. The mission recommends funding of two suitable slow combustion stoves, ovens, and hot water systems for large urban households under the UNDP regional funding. Assistance in their procurement and installation would be provided through the services of the proposed UNDP wood fuels specialist to be available in 1983.

The general issue of wood fuel supply and demand in the domestic sector is discussed in 4.1 and is the subject of a special review of fuelwood production and supply (other than with coconut residues) arranged at the request of the mission (see 4.1.3).

4.6.4 Other cooking aspects. N.A.

4.6.5 Solar water heating. Water heating in the domestic sector can be achieved with either solar water heaters or water heating installed as part of new wood stoves. In general, it is cheaper to install water heating as part of a slow combustion stove. However, where this opportunity does not exist, the government is advised to facilitate the use of solar water heating. For a solar hot water system of 300 litre capacity and 3 m^2 collection area, displacing 2,500 kWhrs of electricity per year, the payback based on the true cost of electricity, rather than the present selling price, is about 1.5 years. The mission recommends that the TEPB (Tonga Electric Power Board) be made responsible for a solar water heating retrofit programme to all electric water heaters in government housing and that this service be available on request to the private sector. The retrofit programme should be an entirely commercial project, with an agreed rate of return to the TEPB above true costs of the management involved. Private sector plumbers would contract for the installation and system maintenance with the TEPB. A five-year repayment scheme with monthly installments is proposed, in which case the uniform monthly payment by the consumer would be expected to be less than the expenditure incurred for the electricity previously used for water heating.

4.6.6 Charcoal irons. Charcoal irons might be encouraged as an alternative to benzine irons. Coconut shell charcoal is most suitable for this purpose. Generally, the cost of charcoal irons is one-third that of kerosene and benzine models and charcoal fuel is also about one-third the price of benzine or kerosene. (In this context, it is interesting that there has been a revival in the use of charcoal irons in Western Samoa recently.)

5. PETROLEUM AND FOSSIL FUELS

5.1 Supply and Storage

5.1.1 Present supply patterns. Most petroleum products are supplied to Tonga by coastal tanker (1,000 to 1,500 DWT) from storage tanks in Fiji. These products originate in refineries in Singapore and Australia (near Melbourne). British Petroleum (BP) brings in aviation and ground products for its own needs and also carries ground products for Shell by arrangement between the companies. The tanker, operating under charter to BP, calls in Tonga about once every six weeks, stopping in Vava'u as well as Nuku'alofa. Tonga is usually part of a journey that includes Western Samoa and Niue. Liquified petroleum gas, originating near Melbourne, is supplied by Boral.

5.1.2 Future supply. The mission noted the interest of Marlex, an American company, in supplying fuels to Tonga from its storage facilities in Pago Pago. The mission encourages the government to consider carefully the potential benefits of this arrangement and has arranged through UNDP for the provision of expert advice on this matter if so desired by the government. (A full review of the government's options has now been undertaken, following a visit by the consultant expert to Tonga. The specific issues and options raised and evaluated are the subject of confidential exchanges betwen the parties and agencies concerned.)

5.1.3 Fuel storage. Bulk storage facilities in Nuku'alofa are owned and operated by Shell and BP. The government owns storage tanks for motor spirit and diesel fuel on Vava'u, which are presently leased to Shell. Total tank capacity at Nuku'alofa and demand coverage (based on 1981 sales) is as follows:

	Tonnes	Demand coverage
Diesel fuel	1396	92 days
Motor spirit	534	63 days
Kerosene	100	66 days
Jet fuel	584	70 days

5.1.4 Future arrangements with fuel storage. The mission recommends examination of the possibility of government purchase of storage facilities, which would facilitate more flexible negotiation of supply contracts. Advice on this matter has also been made available to the government.

5.1.5 Local marketing and distribution. Shell claimed over 70 percent of the total market for ground products in 1981, while BP sold nearly all of the aviation fuel. Mobil serves a small part of the market, utilising Shell storage. Products are delivered to Ha'apai, 'Eua, and other islands by drum from Nuku'alofa.

5.2 Pricing and Price Control

5.2.1 Price composition. The main elements in the buildup of the price motor spirit and diesel from refinery to retail consumer, based on allowed prices of April 1982, are shown below. A similar buildup applies for kerosene. The wholesale and retail prices below are for Tongatapu.

	Motor spirit	Diesel
	(T cents/litre)	
FOB Singapore	23.21	22.66
Freight to Fiji	1.75	1.97
Freight Fiji-Tonga	2.39	2.39
CIF Tonga	31.83	31.40
Wharfage	0.44	0.44
Duty	1.50	1.50
Port tax	3.92	3.87
Sales tax	1.10	0.88
Agency commission	0.22	0.22
Onshore losses	0.19	0.19
Distribution expenses	3.19	3.19
Oil company margin	1.98	1.98
Wholesale price	44.44	43.71
Retail markup	1.56	1.29
Retail	46.00	45.00

(Since the above information was compiled, new wholesale prices of 45.22 T cents/litre for motor spirit and 44.91 T cents/litre for diesel have come into effect.)

5.2.2 Duty. Duty assessed on motor spirit, diesel spirit, diesel fuel, and kerosene is 1.5 T cents/litre. This level of duty is very low (only about 5 percent of the CIF value). The mission believes that some upward revision of the duty on petroleum fuels is warranted since none of the usual objectives of levying duties on petroleum products (such as recovering a road-user charge or indicating the burden of fuel imports on the local economy) is being served at the present duty level.

5.2.3 Price control. Wholesale and retail prices of motor spirit, diesel fuel, and kerosene are controlled by the Ministry of Labour, Commerce, and Industry. Shell and BP each submit requested price changes, and the allowed selling cost (not including margin) is arrived at by taking an average of the respective submitted costs, weighted according to the companies' share of the market for that fuel. A margin currently at 1.98 T cents/litre is added to give the allowed wholesale price. The allowed price is 1 to 2 T cents/litre higher in Vava'u and 4 to 5 T cents/litre higher in Ha'apai.

5.2.4 Price monitoring and negotiation. N.A.

5.2.5 Local marketing and distribution. N.A.

5.3 Resource Development

5.3.1 Overview. The mission has agreed to review these arrangements as part of this energy study, given that much of the critical information is a matter of contract and confidence between the oil companies concerned and the government.

6. ELECTRICITY

6.1 Institutional Arrangements

6.1.1 Overview. Electricity is generated and sold by the Tonga Electric Power Board (TEPB). The TEPB is constituted as a statutory authority with a board of directors appointed by the government. Of the ten-member board, two are Ministers of the Crown, one as Chairman and the other as Deputy Chairman. Consumers are represented on the Board by nomination. The TEPB has a General Manager who doubles as chief engineer and is also secretary to the board and an ex-officio member of the board. It is the responsibility of the TEPB to produce electricity for sale to the public throughout the Kingdom. The government expects the TEPB to be a "commercial" undertaking, meeting its costs from its revenue. Other than this general view (of the Finance Department), the financial and institutional objectives of the TEPB are ill-defined. The TEPB has a monopoly on electrical wiring and servicing electrical installations in Tonga.

6.2 The Power System

6.2.1 Generation system. Production centres are located on Tongatapu, Vava'u, and, recently, Ha'apai. Diesel generation is the only form of production in each. In Tongatapu, one power station (Popua) serves the demand. It has two 1,729 kW, 500 rpm, Mirrlees Blackstone sets, and two 1,198 kW, 428 rpm sets of the same make. The two larger sets were purchased in 1974 and 1980, respectively. The system peak demand of 2,100 kW can be met at all times with one large and one small set on-line. The power station therefore has adequate reserve capacity; indeed the newest 1,729 kW set has to date rarely been used. On Vava'u, a single power station is located at Neiafu. The installed units are three 150 kW Lister-Blackstone medium-speed diesels, with a fourth planned for installation late in 1982. The peak load has been met by one 150 kW unit until 1982. Now two units must be dispatched to the peak which has risen to 210 kW. With an additional 150 kW set installed on a 250 kW gasifier-engine generation set, there will be more than adequate firm capacity to meet demand at current and foreseeable levels during the next decade. A power station was established in Ha'apai during 1980 and 1981.

Two 50 kW, 1,000 rpm, Dorman generators were installed there ready for generation within weeks of Hurricane Isaac. However, more than one-half of the reticulation was damaged by the hurricane although only superficial damage was sustained at the power house. Power production was then delayed to the second half of 1982.

6.2.2 Transmission and distribution. Supply on Tonga is at 240/415 volts. Transmission is mostly at 6.6 kV, although 16 km of the 138 km of high tension distribution is at 11 kV. Distribution lines of 135 km at 415 V connect the load to high tension lines. On Vava'u, transmission is by 19 km of 6.6 kV lines and distribution by 30 km of 415 V lines. Ha'apai transmission and distribution is at the same voltage. Total transmission and distribution losses, based on sales, compared with power sent out have been less than 12 percent until 1981. The transmission system at all supply centres suffered major damage during the hurricane, and disarray will effect "losses" from all causes during reparation. Large sections of the transmission and distribution system on Tongatapu are on wooden poles now rotting and in need of replacement. The power system will remain highly vulnerable to wind damage until this pole renewal programme is complete. All consumers are metered and billed.

6.3 Planning Issues

6.3.1 Overview. Power system planning is hampered by lack of staff and expertise in economic analysis. Plans are made only for three to four years in advance in line with the national development plans coordinated by the planning office. This period is not adequate for forward planning which must be represented by firm plans for the decade to follow and indicative plans for upward of 20 years. All plans should be reviewed and, if necessary, revised annually; they bear a direct and accountable relationship with financial plans specifying revenue objectives and matching sales forecasts and tariffs for the same period. The TEPB should be deeply engrossed in a detailed review of all power generation options besides diesel and of the optimisation of the expansion of the present system, especially the transmission-distribution component.

6.3.2 Options and recommendations. The TEPB does not have access to information on the pattern of sales by consumer class or the nature of demand within major consumer classes, although in each supply centre several large consumers dominate demand. There are many options open to major consumers to reduce their consumption of elecricity in favour of more economic energy forms. Insofar as the alternatives to electric cooking and water heating may significantly reduce the peak demand and may reduce the scale of new investment in wood fueled power systems, it is quite important for the TEPB management to appreciate both the opportunities for, and genuine prospects of, major changes in energy use, affecting the level and timing of electricity demand.

The alternative means of thermal power generation advocated here require a thorough understanding of the nature and extent of wood and cellulosic fuel sources, the constraints applying to their reliable supply, and the likely costs of each class of fuel within and between load centres. It is clear to the mission that this is a complex task which, if undertaken lightly, could have serious financial repercussions. The complexity of defining the new "fuelwood" resource is matched by the difficulty of the administrative task of ensuring effective liaison between these agencies and growers responsible in some way for supply; MAFF, the commodities board, the Oil Mills of Tonga (under possible whole-nut harvesting and centralised copra production to release residue fuels), "api" owners and losses, plantation owners and managers, and sawmillers.

The mission believes that a wood-fueled power system is viable and desirable. However, to implement this alternative requires attention to significant details of future power demands, size, and timing of new generation equipment, fuel sources and costs, and financing and tariff arrangements. The mission concludes that an expansion of the generation system must be made in the context of a thorough ten-year system expansion and financial plan for each supply centre. This will require external assistance, although it is essential, regardless of offshore inputs, to have an economic planner and additional technical power systems planning capacity on the staff of the TEPB to lay the groundwork for comprehensive and systematic planning.

6.4 Management Issues

6.4.1 Overview. The management of the TEPB has been able to provide a secure and cost-effective power supply in difficult circumstances of inadequate staffing and limited financial resources. In the generation area, the power system is well maintained and a high level of security of supply has been ensured with both the Vava'u and Tongatapu power station able to meet peak demand with two of the largest generating units off-line. Until recently, transmission and distribution losses were among the lowest in the region. The management is aware, however, of the deficiencies in the accounting and economic planning areas, and of the need for more extensive forward planning for future system expansion. Many issues of financial management will be dealt with under section 6.5, Electricity Pricing. There are some matters that can be discussed here relating to the broader issue of the relationship between government and the utility which are general questions of management, but with implications for electricity pricing.

6.4.2 Financial management. The mission was concerned that: (1) the government had not specified any rate of return objective for the utility, (2) there was no policy governing the rate at which monies should be on-lent from the government to the utility, whether or not these monies originated from aid donors, and (3) the finance department had not specified general operating conditions of financial management that would affect tariffs, such as debt service ratios.

A quick review of the terms and conditions of loans from the government to the TEPB indicated a wide variation in interest rates, but practically no "hard terms" financing. On a second T$1.4 million loan, the government simply transferred the loan it received from a donor to the TEPB with the same terms: a grace period of five years, repayment over 40 years at 1 percent. In this instance, the government has forgone T$700,000 to $900,000 compared with on-lending this money on more commercial terms and conditions; say, 8 to 10 precent over 15 to 20 years. No particular level of subsidy to the power sector has been agreed by the cabinet, nor has any mechanism for subsidy been agreed. The mission recommends that a policy on subsidy to the power sector be openly discussed by the cabinet with the present level and form of subsidy applying spelled out compared with a fully "commercial" utility operation returning, say, 8 percent real to the government's equity investment. In addition to the soft loans provided, the government subsidises the utility by waiving import duties on diesel and lubricating oil, and by outright gifts of equipment.

6.4.3 Other management issues. N.A.

6.4.4 Recommendations. The mission strongly recommends that the government on-lend to the utility at an agreed "commercial" rate and that a target rate of return of, say, 8 percent (the alleged opportunity cost of capital on the Tongan market) be set so as to determine the revenue objective for the establishment of tariff levels. Unless the interface between government and TEPB is clear and simple on the matters of financial performance, obligations, and accountability, it will be increasingly difficult for the government to monitor and judge the viability of the utility.

As with financial management, there are no stated objectives for the administration, engineering, and personal divisions of the TEPB. The board of the TEPB has only limited knowledge of power sector management and planning and would be greatly assisted in their task of reviewing and guiding the performance of the management if they were able to review progress against a series of both broad and specific objectives: relating to both general goals of the electricity operation and to particular projects and activities for which a budget facility had been arranged. Accordingly, the mission recomends that the board and top management liaise to define, both in broad and specific terms, the goals and objectives of the TEPB, and to document these for reference in comparison with actual performance. As a corollary to this exercise, a management information system should be established by the new staff (6.3.5) to identify movements in cost in the production system as they occur.

The monopoly position of the TEPB over household wiring and electrical installation work generally is financially to the TEPB's favour. A standard markup on costs of 25.5 percent is applied. It is not clear, however, that the community is receiving the cheapest service through this monopoly arrangement. The obligation borne by the TEPB to service this business is apparently burdensome and interferes with the regular maintenance and operations of the power system in the present situation of deficient staffing. The mission urges a review by the government as to whether this monopoly position should be preserved. The cost is several cents per kWh in revenue for the TEPB, and the benefits are a reduced administrative burden for the utility, and lower prices for the service due to competition between a number of local entrepreneurs who are reported to be prepared to enter the electrical service industry.

6.5 Electricity Pricing

6.5.1 Overview. The mission reviewed the costs of production in both Vava'u and Tongatapu and compared these with the price structure and level being applied in March 1982. On Tongatapu, the mission's estimate of the full marginal cost of supply (allowing for 8 percent return on capital and after deducting secondary revenue) is 26.3 cents/kWh, and for Vava'u 40.1 cents/kWh with an average over the TEPB system of 27.6 cents/kWh (see Appendix 6.5.1 for details). These costs compare with the selling price for the first 525 kWh of 19.07 and 19.51 cents/kWh, respectively. An approximate estimate of revenue from sales of electricity 1982/83 under the existing tariff is T$1.65 million, some T$0.9 million below the cost of supply. This level of subsidy is very considerable, although it is largely hidden by the *de facto* policy of "soft" financing of the power sector and the failure to recover the capital invested, or a return on it, so that all replacement of equipment and system expansion must be financed directly from the government's budget.

6.5.2 Present tarrifs. In section 6.4, we noted our concern that the government was subsidising the TEPB heavily through passing concessionary financing from aid donors directly on to electricity consumers, and we recommend strongly against this practice. The policy issue at stake is that of equitable distribution of the available development expenditure. Electricity consumers accounting for the majority of domestic consumption are by and large the most affluent members of the community. The government may perceive some benefit in extending to this group a heavy subsidy through artifically low power charges, but it would, in any case, be an advantage to know the extent, and the opportunity cost, of that subsidy. By not charging the full marginal cost of production to the group most able to invest in more economic alternatives, considerable opportunities to use local, rather than imported, fuels are lost. It is clear, for example, that solar water heating and wood and charcoal cooking and water heating are markedly cheaper than diesel-generated electricity and, with proper demonstration and promotion, could generate both local employment and indirect benefits to the agricultural sector. Similarly, the growth in demand for electricity, and hence for imported diesel, is certainly higher than would be the case if the full costs of production were charged. In the likely event that foreign exchange becomes scarce, this distortion through incorrect pricing will prove even more costly.

6.5.3 Other tariff issues. N.A.

6.5.4 Recommendations. An adequate tariff should: reflect the true cost of production at the margin; encourage the use of the most economic energy form in each sector and end-use and the efficient use of power; be simple to understand and administer; and meet the pre-determined revenue objective. In a self-financing utility, the revenue should also be sufficient to provide adequate equity to attract the necessary debt to finance replacement and expansion as needed. The mission appreciates the sensitivity of the cabinet to further and marked increases in electricity tariffs, especially so soon after a natural disaster. However, tariff structures can quite legitimately serve social and political objectives, provided the costs are known and the overall revenue objective is still met. The mission has therefore developed a tariff structure to demonstrate the potential to go some way toward meeting the objectives of an economic tariff defined above, while allowing electricity costs to remain the same or be reduced for a significant number of low-income consumers.

The tariff devised by the mission is an economic tariff with a "life-line" block (see Appendix 6.5.4 for details). A "life-line" block is a quantity of electricity adequate for meeting basic services in a particular environment. It is usually a small amount of power and is sold at below the cost of production. In the tariff described here, the "life-line" block is 50 kWhrs per month, an amount adequate for a few lights and small appliances, and these units are sold for 15 cents/kWh (with a minimum charge applying). Under present consumption patterns, the described tariff would result in a reduced average bill for nearly 70 percent of all consumers, yet would increase revenue in 1982/83 by some T$500,000 relative to the existing tariff. This is because all units above the "life-line" block would be sold at the system's average full cost of supply: about 28 cents/kWh. Approximately one-fourth of ll units would be sold at the "life-line" rate, resulting in a "subsidy" of about T$280,000 to small consumers. The subsidy could be reduced by lowering the boundary of the "life-line" block.

As analysed here, the same tariff applies to all customers in all locations. In reality, of course, there are differences in the cost of supply both within each island system and between sytsems (i.e., Tongatapu and Vava'u). Although economic principles can serve as a guide, the distribution of costs among consumers is to a large extent a political decision. The mission's prime concern is that overall the tariff should be sufficient to place the TEPB on a sound financial footing, but it is also important that consumers be aware of the true cost of their electricity. If it is decided that uniform pricing throughout Tonga should apply for reasons of social equity, it is important that investment and policy decision regarding electricity production and use in the outer islands take account of the true rather than the nominal cost of power.

Impact of price rises on industrial and commercial undertakings. The tariff described above represents a substantial increase for large consumers, and the government will, no doubt, experience considerable pressure from large enterprises to keep the price of electricity at its present level. There have alredy been requests made within government for lower electricity prices than those now prevailing for selected small manufacturing ventures. The mission strongly recommends that the government does not use electricity pricing as the vehicle for protecting the manufacturing sector or other sectors. The more appropriate approach, in our view, is to examine the overall costs of production for an enterprise claiming the need for lower electricity prices and to determine whether assistance is indeed warranted in each case. If some form of assistance is required, it should be provided by more direct means, for if electricity prices to that enterprise are lowered, there will be a much reduced incentive to eliminate wasteful consumption or to switch to more economic fuels where the opportunity exists.

6.6 Rural Electrification

6.6.1 Overview. Approximately 20 percent of Tonga's population live on islands not presently supplied with TEPB power, although Lifuka in the Ha'apai group and 'Eua will shortly receive diesel fueled electricity. Section 4.5 examines the opportunities to produce electricity on a small scale roughly competitive with diesel generation. There are good prospects of reducing the need for further diesel power systems to provide small amounts of power in the outer islands, and thereby alleviate the growing burden of maintenance and administration that the TEPB is experiencing with the establishment of smaller supply centres. However, there remains the issue of how to meet industrial and commercial demands in these high-cost centres without incurring a large and growing debt.

6.6.2 Recommendations. In strict financial terms, the most appropriate measure for the TEPB would be to raise tariffs in the outer island supply centres until they more closely reflected the true cost of production. The mission appreciates, however, that this approach may conflict with the government's desire to provide some equity between the cost of living in the more remote areas and that in Tongatapu. Accordingly, the mission recommends that whenever a major private enterprise demands a power supply from the TEPB in an outer island, it loans the capital at agreed rates for the power house expansion required and pays a rate for supplying matching the full costs of production to the TEPB. Any support warranted to establish the industry in a remote centre should be negotiated directly between the enterprise and the government. Again, any attempt to reduce the cost of electricity directly will result in a less than optimal use of electricity and potentially cheaper sources of energy.

7. ENERGY CONSERVATION AND MANAGEMENT

7.1 Opportunities for Energy Savings

7.1.1 Households. Measures taken to consume energy in this sector should complement a rational pricing policy for electricity and other fuels. Commonly, there is an inadequate knowledge of opportunities to manage appliances for maximum efficiency. Householders should be informed of opportunities for saving electricity by proper use of stoves and refrigeration, and should be aided in their selection of appliances by appropriate labeling including the cost of operating appliances under specified conditions. The TEPB is ideally placed to lead this programme through its sale centres and to undertake a publicity campaign on simple measures to save power and money. The most commonly observed lighting in small homes and shops was incandescent globes, whereas fluorescent tubes use less than one-third the amount of electricity. The TEPB should use its authority to influence this lighting pattern.

7.1.2 Lighting. Street lighting in Tonga can be switched to sodium vapour lamps with considerable savings in energy per unit light output. The priority of a retrofit programme will depend on the general rehabilitation of the transmission and distribution system after Hurricane Isaac. However, the mission recommends a review of street lighting by the TEPB given the considerable savings that can occur with incandescent fittings still in use in parts of urban areas.

7.1.3 Refrigeration and cooling. N.A.

7.1.4 Transportation. Most of the practical measures for conservation in this section are within the ambit of government regulation with the intention to improve the overall efficiency of the fleet or road vehicles. However, with the assistance of an energy planning unit, the shipping corporation and other agencies utilising large marine craft can be appraised of patterns of vehicle use conducive to higher efficiency of fuel use, as well as matters of "craft design" and engine and propeller sizing, which greatly influence the work output per unit of energy consumed. There is a prospect of worthwhile savings for heavier slow speed marine diesels in switching to a heavier grade of fuel (No. 2 or No. 4 or blends) depending on the compatibility of the existing motors with the use of these fuels. Savings of 2 to 3 cents/litre can be achieved if oil companies are prepared to supply the heavier grade of diesel fuel. The availability and short- and long-term cost of heavier fuels for larger diesel engines should be a matter of discussion with potential contractors when the government and large companies are negotiating a supply of oil products (see section 5). The mission views the use of heavier marine fuels including, in the longer term, the use of fuel oil (No. 6) as sufficiently promising to warrant a regional review of the costs and benefits and has recommended the use of UNDP regional energy funds for this purpose.

7.1.5 Industry and commerce. N.A.

7.1.6 Building codes. For the formal housing sector, building regulation are inadequate. They emphasize safety and durability, but ignore thermal comfort. Housing can be designed to make better use of both natural illumination and ventilation and to reduce solar gain. The Central Planning Office has been provided with an example of suitably modified building codes adapted for low-energy use in a tropical environment.

Industrial and commercial building codes can be subject to the same reform. The mission observed both extremes of buildings in a tropical climate while in Tonga: the government office building that housed the MAFF and other departments was well ventilated and illuminated without artificial support, whereas the rooms in the Dateline Hotel in the same physical environment had to be air conditioned and fully lighted with electricity to be comfortable. Relatively simple and inexpensive, even though elegant, designs of new major buildings can greatly reduce these energy demands for the same commercial facility.

Energy audit of existing major buildings in Tonga will prove financially rewarding. The mission recognised many wasteful and expensive practices of energy use with quite simple and inexpensive solutions; for example, the scalding temperature in the Dateline Hotel hot water system required only thermostat adjustment. However, banks of fluorescent lights next to windows in some government office buildings is another matter. The mission recommends the use of UNDP funds for an energy audit of a major building in Tonga to demonstrate the potential savings.

7.1.7 Energy audits. N.A.

7.2 Government Measures

7.2.1 Energy pricing. The government is frequently either the major energy consumer or a shareholder or benefactor of an industrial, commercial service. In these instances, there is rarely individual or managerial accountability for energy costs, and the pressure of prices may not lead to beneficial change. In the case of electricity, the government as producer is significantly underpricing the commodity with the obvious effect of encouraging the use of electricity at the expense of more economic and locally available energy forms. In recognising these circumstances and the economic choices, the government can equally encourage more rational patterns of consumption to the great advantage of the local economy. The mission would much prefer that the government charged the full cost of electricity at each supply centre, and changed administrative procedures to bring a much greater measure of individual accountability for energy use among public servants and managers of partly- or wholly-owned authorities and companies. However, we recognise that constraints exist and must be faced. Given these circumstances, we recommend direct intervention as follows:

(1) Banning new installations of electric cooking, water heating, and drying (except fans) in the islands other than Tongatapu.

(2) Replacing any failed electric water heater and cooker with solar and/or wood fueled appliances throughout the TEPB supply areas.

(3) Drawing up strict guidelines for the use of air conditioning in the government sector and reviewing all existing uses of air conditioning.

(4) Establishing building standards for insulation and fenestration, etc., for air conditioning buildings, and for circumstances in which air conditioning will be permitted for the private sector.

(5) Facilitating a solar hot water system retrofit programme for both the government and private sectors (see 4.6.9).

7.2.2 Legislative controls. In the transport sector, the mission recommends that the government should slowly restructure the road vehicle fleet by levying prohibitively heavy import duties against large sedan vehicles (over 2,000 cc) and by adopting a steeply sliding scale of duties for sedan vehicles for private use below that level. Preferably, such action would compliment, and be in parallel with, a reform in the levels of duty charged on petroleum fuels (see section 5.4).

8. ENERGY ADMINISTRATION AND PLANNING

8.1 Present Arrangements

8.1.1 Overview. The administration of energy policy and planning is undertaken by the Department of Lands, Surveys, and Environment (DLSE). Policies and plans are considered and determined by the National Energy Committee (NEC) under the chairmanship of the Deputy Prime Minister and Minister for Lands, Surveys, and Environment. The NEC has wide representation, including two other Ministers of the Crown, (Police and Education, Works and Civil Aviation), the public service heads of Finance, Labour, Commerce and Industries, Land Surveys and National Resources, Agriculture, Planning, the Crown Solicitor, and the General Manager of the TEPB. There are four private sector companies, including an oil company, represented on the committee, and a general representative of the private sector. The membership of the NEC and the TEPB board overlap. The management of the TEPB has been directed by the board to identify, evaluate, and implement various renewable energy technologies. The TEPB has not had the staff or financial resources to respond to this directive. Within the DLSE there is no separate division or unit assigned to energy policy and planning. One individual with primary responsibility for other matters had been appointed to take care of administrative matters of an energy nature, and had been dispatched to represent the government in regional energy meetings. The head of the DLSE had also taken a direct interest in the energy sector. There is no comprehensive energy policy, and despite two years of meetings, the NEC has been unable to achieve any changes of substance in the energy economy. In this context of little reform or action, the government has welcomed the review of the energy sector and specifically sought guidance on the formulation of an effective energy administration.

8.2 Issues and Options

8.2.1 Overview. The role of the TEPB must be clarified. The management must be concerned solely with producing and distributing electricity, preferably as a "commercial" undertaking. Policy direction for the TEPB must come from the government, as the owner, and preferably through the agency of the NEC, and the cabinet. The policy context of power sector development is appropriately a national energy policy covering the integrated development of the entire energy economy from petroleum to renewables. The management of the TEPB has no desire to be involved in determining energy policy other than through consultation on the implication for various policy choices for the TEPB, and clearly there is no specific staff of the TEPB to fulfill the role of an energy planner. However, the TEPB must liaise and cooperate closely with an energy policy and planning authority, and it is appropriate that the General Manager sits on the NEC. The mission has recommended that the goals and objectives of the TEPB be spelled out so as to clarify the direction of desirable change within the power sector, specify the nature of the relationship between the government (through its various departments and agencies) and the TEPB, and to enable the performance of the TEPB to be better monitored (see 6.4). This exercise must compliment the formulation of policy for the energy sector as a whole.

8.2.2 The role of the energy planning unit. In the mission's view, an energy planning unit should be formed as a matter of urgency. It is clear from our review of the energy economy that there are a great many prospects for the economic production or conversion of locally available energy forms and many opportunities for the more cost-effective utilisation of imported petroleum products. In addition, the regional multilateral aid agencies and SPEC have funded both regional administration and major projects and programmes, many of which stand to directly benefit Tonga. However, without a focal point for integration and communication, locally and internationally, few of the obviously beneficial programmes and projects can be initiated and sustained. An energy planning unit need be of no more than three professionals; an economist/analyst manager, an engineer, and a biological scientist (forestor, agriculturalist, biologist) (see Appendix 8.2.2). The mission has been appraised, however, of the difficulty of getting even one post established; but clearly, at least one appointment is essential.

The role of an energy planning unit is to analyse, integrate, and propose policies for the energy sector which deal with both management and production, and which are both internally consistent and compatible with the overall development strategy of the government and with other sectoral policies and programmes. It is evident, for example, that the energy future of Tonga should increasingly feature the use of coconut wood and waste, and that this development can greatly compliment the efforts of MAFF to regenerate an aging stand of coconuts and to derive maximum economic benefits from this declining industry. The role of the Energy Planning Unit (EPU) here is to identify economic uses of coconut-derived energy forms region by region and to advise MAFF on the implementation of "coconut-energy" production programmes as agreed. The EPU should not be an implementing body and should only spawn an implementing agency if the existing departments responsible for implementation are unable to cope with the additional burden of energy-related projects and programmes.

8.2.3 A National Energy Committee (NEC). An EPU would act as the secretariat to the NEC. A big deficiency in the current deliberations of the NEC is that: (1) they lack a policy context and (2) they are not serviced by previous well documented arguments and options on which to focus discussions.

The first step is to agree on a policy, no matter how brief, which recognises that opportunities for improved economic production and management exist in the energy sector that need to be facilitated by formal recognition, encouragement, and in some cases positive government inducement. Many such projects, programmes, and policies are outlined in this mission report. The next step is to create the administrative capacity to analyse and define the relative merits of utilising scarce government resources in any of a wide range of possible activities. And the final step is to have quite specific proposals placed before the NEC and then the cabinet for endorsement for funding and implementation. Energy policy and planning is not a static function. An EPU must continually brief the NEC on changes in the energy economy regarding their significance to the national economy, as well as existing policies and programmes. The NEC must also be regularly appraised of the performance of programmes agreed upon and the impact of policies they have adopted. To enable this relationship between the EPU and the NEC to develop and bear fruit, it is desirable for the head of the Energy Planning Unit to be the administrative secretary of the NEC and for there to be regular meetings at which some matters are discussed as a matter of course, apart from items of special business. Submissions and reports to the NEC should have a standard format and should pass through the EPU for review.

A major task of an EPU is to define the resource base from which energy of the lowest cost can be drawn. Effort should be expended on the inventory of a resource to the extent that it is believed that it will make a contribution to the energy economy in the next 10 to 20 years. The most effort should be made to define the costs and benefits arising from the use of energy forms and conversion technology believed now to be economic. One such energy resource is the coconut crop, including the standing biomass. In the resource overview, the mission estimated the various classes of coconut wastes and timber using the data available. However, the data are clearly deficient. The mission recommends, as a matter of high priority, that MAFF, and should it exist, the EPU, undertake or commission a detailed study of the present use, and present and possible future availability of all classes of coconut-derived fuels (including stems, husks, shells, leaf sheath, and fronds) and identify the cost of each class of fuel delivered in various forms to potential demand centres and the implications of their commercial consumption compared with any current informal exchange and use by households and smallholders. The theoretical surpluses of these classes of fuel dwarf the maximum foreseeable demand, but no confidence can be invested in their true availability or delivered price until a more detailed study is made.

8.2.4 National coordination. N.A.

Appendix: 3.1.4

PETROLEUM FUEL CONSUMPTION IN 1981

This appendix refers specifically to the breakdown of fuel use in Table 3.2. Fuel used in inter-island shipping and air transport (estimated) is included, but fuel used in international transport is not. Total energy use for each fuel refers to market sales as reported by the suppliers.

Household uses

All kerosene and white benzine is allocated to this purpose, though there may be minor miscellaneous uses as well. Two-thirds of total LPG use is estimated as the household share.

Transportation

The amount of diesel fuel used in transportation is estimated by subtracting diesel use in heat/steam-raising and electricity generation from total use, with the additional subtraction of a small amount used for other purposes. Almost all motor spirit (some of which is used in subsistence and small-scale commercial fishing) and all avgas are allocated to this purpose. The amount of jet fuel used internally was estimated by BP.

Heat steam-raising

1981 fuel consumption by various consumers was estimated from information collected. Consumers included are the oil mill, the hospital, the main bakery, and several colleges and high schools.

Electricity generation

Included is diesel fuel used by the TEPB on Tongatapu and Vava'u. A small amount (50 kl) is added for fuel use in small private diesel generators.

Other

This heading includes estimated diesel fuel use in construction and agriculture/forestry equipment, as well as petrol used in chainsaws.

Appendix: 3.3.1

BIOMASS ENERGY USE

Domestic cooking

Most Tongan households use biomass fuels (wood and coconut husk and shell) for everyday cooking. We assume here that 80% of rural households biomass fuels only and another 10% use biomass supplemented with kerosene (75% wood, 25% kerosene). For Nuku'alofa, we assume 50% of the households use biomass only and 25% supplement biomass with kerosene or gas. Finally, we assume that 95% of all households make an umu on Sundays.

The quantities of biomass used in cooking are not accurately known. We were told by women that generally only the husk and shell that is around the house from nuts used for domestic purposes is used in cooking. Wood is also gathered. In addition to this husk and shell, considerable quantities are purchased from the dessicated coconut factory by urban residents. Wood is also sold in the Nuku'alofa market. In the absence of reliable survey data, we will apply Fijian survey data and assume that everyday cooking with biomass only consumes 400 kg/head/year (oven-dry weight). We also use Fijian data for biomass use in the umu: 1 kg/head/umu.

In our calculations we use a total population of 98,000 and a Nuku'alofa population of 20,000.

Based on the above considerations, we arrive at the following results:

	Oven-dry tonnes
Normal cooking	
Rural	27,300
Nuku'alofa	5,500
Umu	4,800
Total	37,600

Using an energy content of 19 MJ/kg, energy consumption equals:

37,600 ODte x 19 GJ/ODte = 714 TJ

Copra drying

We estimate that about two-thirds of the available husk and shell are burnt to dry copra. (The remainder are used for pathways and landfill for cooking, or are left in the field.) Assuming that 1 tonne of copra requires 6000 nuts weighing 1 kg each, and that each nut is 60% husk and shell by weight (average of Fijian and Samoan nuts), then 3.5 te of husk and shell are available for each tonne of copra produced. Two-thirds of this is about 2.3 te. With 1981 copra production of 11,234 te, this amounts to 25,800 te of husk and shell. We assume that husk and shell are burnt together, and have an energy content of 11.6 MJ/kg (as received). Thus energy consumption equals:

25,800 te x 11.6 GJ/te = 299 TJ

Appendix: 4.1.3(a)

TONGA'S COCONUT HUSK AND SHELL RESOURCES

(a) Husk and shell available at dessicated coconut factory

Parameters

- New factory will process 15 million nuts per year at site compared with 7.2 million nuts in 1980 and 7.9 million purchased by Commodities Board in 1981.
- The average Tongan coconut weighs 1.2 kg and is made up as follows: (percentages by weight, based on mission measurements)

Husk	Shell	Meat	Water
37 (28.6% m.c.w.b.)	14 (13.8% m.c.w.b.)	27	23

Total residues

(1) Husk: 6,600 te (as received)
4,755 ODte

(2) Shell: 2,520 te (as received)
2,170 ODte

Sales in 1981 of husk and shell

(1) Husk: T.$2217 at $2/"2 tonne truckload" (est. at 1 te/truck actual weight)
Sales were thus about 1100 te

(2) Shell: T$2537 at $2.50/"2 tonne truck" (est. at 1.5 te actual weight)
Sales were thus about 1500 te

(b) Husk and shell available from whole nut harvesting and centralised copre drying:

Parameters

- Assume that 1981 copra production is typical of future yields. Production data are (in tonnes):

Tongatapu	Ha'apai	Vava'u	Eua and Niuas
6174	1870	2437	325/378

- Centralized drying using efficient hot-air generators/gasifiers requires approximately 500 kg husk and shell combined per tonne of copra produced.

- Tongan coconuts yield an estimated 2.6 kg husk and 1.0 kg shell per kg copra produced.

- Allowing for 20% losses of husk and shell in wastage, additional home use and unrecovered quantities, available husk and shell nett of copra drying per tonne of copra is:
  (2.6 kg husk + 1.0 kg shell) x 0.8 (recoverable proportion)
  - 0.5 kg (per drier) = 2.4 kg.

- Thus theoretical availability of husk and shell (net of drying requirements) at central processing/drying facilities assuming whole nut harvesting for all purposes is (in tonnes)

	Husk and shell	
	As received 37% m.c.w.b.	Oven dried
Tongatapu;	14,800	9,300
Vava'u:	5,800	3,700
Ha'Apai:	4,500	2,800
Eua and Nuias	1,800	1,100
TOTAL	26,900	16,900

Appendix: 4.1.3(b)

COCONUT STEMS AS AN ENERGY RESOURCE

(a) The coconut palm resource, prior to 'Hurricane Isaac'

- The recent MAFF survey gives a total coconut palm population of about 5 million on an area of 40,000 ha. Of this total, 12% are regarded as senile (ready for sawmilling in 0-5 years), 14% are regarded as senescent (ready for sawmilling in 6-10 years), and 19% are regarded as "old mature" (ready for sawmilling in 11-15 years).

- The given distribution of these trees among the island groups is as follows ('000 palms):

	Tongatapu	Vava'u	Ha'apai	Eua & Niue	Total
Senile	251	151	148	38	588
Senescent	360	205	100	46	711
Old mature	410	317	171	62	960
	1,021	673	419	146	2,259
% :	45	30	19	6	100

- No data exist on tree volume, weight, height and moisture content for Tongan palms, although it is understood that this information will be compiled soon with FAO assistance. In the absence of Tongan data, data for W. Samoa are applied (based on the work described in Leyland, Noble and Watson (1978)). Field observation in Tonga by the mission gave no reason to vary the Samoan data for the purposes of this crude energy resource review. Thus, palm trees are taken as 1059 kg recoverable weight (0.96 m^3 recoverable volume) and of 56% m.c.w.b..

(b) Gross energy resource in senile palms

- Using only senile palms, an annual yield of timber of 145,000 m^3 can be sustained for 15 years.

- Gross energy content: $145 \ m^3 \times 1.06 \ te/m^3 \times 8.6 \ GJ/te =$ 1320 terajoules (TJ)

- Converted to electricity: 1320 TJ gross energy, converted at 12% efficiency yields about 44 GWh. Distribution by location of the senile palms thus provides Tongatapu, 19.8 GWh; Vava'u, 13.2 GWh; Ha'apai, 8.3 GWh, and 2.6 GWH for the remainder.

- The MAFF plans an annual average cull of 80,000 trees (Tongatapu, 35,000; Vava'u, 20,500; Ha'apai, 19,500; Rest of Tonga, 5000), equivalent to about half of the above figure.

- Under the MAFF culling programme the primary energy available annually is:
  80,000 palms x 1.06 te/palm x 8.6 GJ/te = 730 TJ,
  or 24.3 GWh if converted to electricity.
  Distribution of the palms to be culled gives Tongatapu, 10.6 GWh; Vava'u, 6.2 GWh; Ha'apai, 5.9 GWh; and 1.6 GWh for the remainder.

- The gross energy available from the 15 year yield is 2.2 times the petroleum demand in 1981, and the MAFF sustained yield is 1.2 times this figure. These energy values cannot, however, be quoted directly with the petroleum import data, much of which refers to liquid fuels for transportation, and for which there is no economic or generally acceptable substitute based on wood and cellulosic residues.

(c) Energy resource nett of timber

- Utilization of coconut logs for timber can involve varying levels of recovery of the tree stems, depending on the quality of the sawn timber demanded and the potential use of smaller diamater and bent logs for poles, fenceposts and similar products.

- The range may be from one 2-4 m sawlog per tree with a recovery of 30%, say 0.04 m^3; or about 4% of total volume, to 3 x 3.7 m poles with a 40% recovery, or 0.2 m^3; about 21% recovery.

- With many trees assuming a bent and twisted pattern of growth it is reasonable to assume that a recovery of 10-15% is realisable in practice.

- Assuming 15% recovery on true volume of palm tree bole for commercial and community uses the timber and fuel elements of the two means of specifying annual yield in the medium term (15 years) indicated above is as follows:

  (a) 15 year yield: 144,619 m^3/yr total

  i. Fuelwood is 122,926 m^3
  ii. Timber is 21,693 m^3

  (b) Sustained yield: 76,800 m^3/yr. total.

  i. Fuelwood: 65,280 m^3
  ii. Timber: 11,520 m^3

- The imports of timber in all forms to Tonga are available only in dollar rather than volume values. It is most likely that they are within the range 5000-10,000 m^3, corresponding to only \$150-300 m^3 for all products. Clearly not all imported products could be substituted with coconut timber products. In effect, a 15% recovery of coconut tree bole for sawlog would satisfy the local demand for imported timber to the extent that import substitution is practical.

Standardised to oven dry weights the potential coconut palm stem resource, after timber extractions, is approximated as following:

	15 year harvest	Sustained harvest
	(Oven Dry Tonnes)	
Tongatapu	23,600	12,570
Vava'u	13,860	7,360
Ha'apai	13,180	7,000
Eua and Niuas	3,380	1,800
	54,020	28,730

Appendix: 4.1.5(a)

ENERGY THEORETICALLY RECOVERABLE FROM DAMAGED STEMS FOLLOWING HURRICANE ISAAC

- Data used here are adopted directly from an FAO review shortly after the hurricane occurred.
- The number of trees stated as the total population refers to the trees on 'apia' only and excludes the 37 plantations covering 1716 ha on Tongatapu, 437 ha on Vava'u and 50 ha on Ha'apai. The population of trees on these plantations accounts for the difference between the totals given below (from FAO) and those used in Appendix 4.1.3(b). The 'api' data is based on the 1979 survey of MAFF.

Coconut trees damaged by Hurricane Isaac

Population figures based on the 1979 survey of standing coconut palms.

TONGATAPU (reliable estimates)	%	Actual
Total coconut palm population	100.0	2,158,000
DAMAGED BY HURRICANE		
Uprooted	3.475	75,000
Damaged beyond regeneration	0.324	7,000
Total damaged	3.8	82,000
Suitable for timber (76% of damaged)	2.873	62,000

Assume one sawlog per tree @ 2.4 m length by 0.254 diameter is obtainable per tree ∴ total volume as input to saws - $7,540m^3$ @ 30% recovery - as sawn timber for structural use - $2,260m^3$.

HA'APAI (Tentative estimates)	%	Actual
Total coconut palm population	100.0	974,000
Damaged by HURRICANE		
Uprooted	-	-
Possible total damaged	15.9	154,900
Suitable for timber (estimated 52%)	8.2	80,000
= $9,700m^3$ input @ 30% recovery = as sawntimber		$2,900m^3$

VAVA'U (tentative estimates)	%	Actual
Total coconut palm population	100.0	1,252,000
DAMAGED BY HURRICANE		
Uprooted	-	-
Other damage	-	-
Possible total damaged	12.5	156,500
Suitable for timber (as Tongatapu)	9.5	119,000
$14,470m^3$ input @ 30% recovery = as sawntimber		$4,340m^3$
	Total	$9,500m^3$

Total trees damaged

	No's	Volume (est) (m^3)	Fuelwood portion (te as received)
Tongatapu	226,000	216,960	236,841
Vava'u	156,900	150,624	162,940
Ha'apai	154,900	148,704	159,234
TOTAL	537,800	516,288	559,015

(At 56% m.c.w.b. nominal standard)

- Total as oven dry tonnes: 250,000
- Percentage of total palm population damaged: 11%
- Theoretical maximum charcoal production nett of sawn timber recovery:-
  246,000 ODte x 0.25 (conversion efficiency to charcoal)
  = 61,500 te charcoal (equal to 1850 terajoules at 30 GJ/te)
- Electricity production potential of above charcoal production.

(1) By steam: $1850 \text{ TJ} \times 0.12 \text{ (efficiency)} \times \frac{1 \text{ kWh}}{3.6 \text{ MJ}} = 61.5 \text{ GWh}$

(2) By gasification: $1850 \text{ TJ} \times 0.2 \text{ (efficiency)} \times \frac{1 \text{ kWh}}{3.6 \text{ MJ}} = 102.5 \text{ GWh}$

Appendix: 4.1.5(b)

PATTERNS OF CHARCOAL PRODUCTION FROM COCONUT LOG WOOD; TONGA

(Note: All costs are in T$)

(a) Log Harvesting

- Harvesting is assumed to be in apis with high density knock-down: 20-40 trees per 8.25 acres (3.33 ha), felled randomly throughout the api.

- Operations are based on 40 trees yielding 3.73 te charcoal.*

(1) Gathering whole logs: Tractor and chain with driver and labourer.

One day to pull up logs to central point in api or nearby road

Costs:

Tractor - fuel charge @ $2.84/hr for 7 hours	$19.88
- capital charges (5 yrs @ 10%)	15.30
- maintenance per day	4.00
Labour- driver @ $4/day (7 hrs)	4.00
- labourers @ $4/day (7 hrs)	4.00

$47.18 OR 12.65/te charcoal

(2) Cutting whole logs: Chainsaws cut trees into one metre lengths (20 cuts/tree). Chainsaw operates 6 hours/day making 1000 cuts.

Costs:

Chainsaw total costs including maintenance and fuel @ $800/6 months or125 days: $6.40/chainsaw/day.

• Two chainsaws in operation	$12.80
• Capital charges per chainsaw $1.80/day	$ 3.60
Labour - 2 chainsaw operators - 4 men stacking timber all at $4/day	$24.00
TOTAL	$40.40 OR 10.83/te charcoal.

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*One tree = $0.96 m^3$; basic density is 486 kg/m^3; 20% conversion efficiency to charcoal (i.e. 1 tonne OD wood = 200 kg charcoal. Thus, 10.72 trees gives one tonne charcoal.

(3) Docking of logs for carbonising:

- Docking saw on back of tractor* cuts 1 metre air-dried lengths into four pieces 25 cm long, i.e. 3 cuts; forty logs per day.

- Air-dried logs in one metre lengths have reached 40% m.c.w.b. or less after three months in the heap.

Costs

• Docking saw owning costs $2,500	
5 year life and 10% discount rate, 250 day year	$2.55
• Maintenance, including blade replacement	3.00
• Tractor fuel charges per four hours ($11.36), capital charges ($15.30) maintenance ($4.00), for one day	30.66
• Labour - four men including tractor saw power operator @ $4/day	16.00
	52.16 OR 13.98/te charcoal

(4) Carbonising: 2 TPI kilns produce 400 kg charcoal each loading two dry tonnes (net of firing residues) on about 4.2 m^3 solid volume (6-8 m^3) stacked volume (kiln volume is 8.5 m^3).

- Charcoal from 40 trees will take two working weeks firing time, at $4/day/man and one man per kiln, i.e. 5 mandays/te charcoal $80.00 OR 21.45/te charcoal.

(5) Bagging - bagging charcoal after passing over wire screen (to 1.5 cm)

- Time and labour is included in kilning operation

- Bags are copra bags or equivalent.

Costs:

Bags and string, 20¢ each and 50/tonne $74.60 OR 20.00/te charcoal.

(6) Loading and despatching to store and unloading into store

- Assume that charcoal collection is done on basis of team collecting several 'api' stacks when the accumulated volume warrants full day operation.

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*"Tractor" includes heavy duty trailer, (4 wheeled), and docking saw held on three point linkage with a belt device and pulley attachment for saw drive. Saw is thin tungsten-tipped.

. Three men and driver are used for three 20 mile round trips per day with half hour loading and unloading for five tonne loads (250 bags each).

Truck hire - T$2/mile	120.00
- labourers 4 @ $4	16.00
	136.00 OR 9.07/te charcoal.

. Charcoal kiln charges; life of kiln is taken as 150 te charcoal over 3 years produced. Cost is T$2000 - or $16.08/te charcoal.

Direct costs per 'sample' Api operation	per $ charcoal
(1. through 6. combined)	87.98
Plus kiln capital charge	16.08
cost per tonne charcoal	$104.06

(b) Reduced 'api' operation:

. Assumes that as part of the 'log cleaning' system there are heaps of dry or partly 'charred' logs one metre lengths ready for carbonisation.

Thus 'costs are only items 3. through 6. above, i.e. per te charcoal

3.	Docking operation	$13.98
4.	Carbonising, screening and bagging	21.45
5.	Bagging, loading, despatching and unloading	9.07
		$64.60
	Plus kiln capital charges (3 yrs life, 10% discount rate)	16.08
	Total per tonne charcoal	$80.58

(c) Sawmill based operation:

Assumes that suitably split material is available air-dried to less than 40% m.c.w.b., and is only in need of docking to fit in kiln (1 metre lengths).

1. Docking - one hour per stacked m^3 of material to reduced length to roughly 1m.

   . Take 7 m^3 material per kiln on one day @ $4/day labour, and $2 saw costs $15/tonne charcoal

2. Carbonising: 1 man/kiln/day for loading, unloading (screening) and bagging. 2000/tonne charcoal

3. Bags: 20¢/20 kg bag $20.00/tonne

4. Loading, despatching, unloading

(assume remote sawmill)	$ 9.07/te charcoal
Total direct costs	$64.07
Kiln charges	16.08
	$80.15

d) Summary of Production Costs

Type of operation	Total costs (FIS) (T$)	Margin @ $120/te (T$)	(T$/tree)	Margin @ $150/te charcoal (T$)	(T$/tree)
A. 'Api' cleaning operation	104.06	15.94	1.49	45.94	4.29
B. Reduced 'api' operations	80.58	39.42	3.68	59.42	6.48
C. Sawmill-based carbonisation of coconut log offcuts	80.15	39.85	3.72	69.85	6.52

Appendix: 4.2.3(a)

WOOD AND CHARCOAL GASIFICATION AS A SOURCE OF POWER FOR THE VAVA'U POWER STATION, TONGA

a) Gasifier retrofit: 150 kW.

Parameters

- A custom designed 150 kw gasifier system with good quality gas cleaning is retrofitted to two 150 kW Blackstone-Lister diesels in the Vavau power house. Switching between diesels is by simple butterfly valve.
- Gasifier cost is T$450/kW CIF Vavau, OR T$67,500.
- Gasifier fuel handling system: storage bins, conveyer system, fuel grading system for both husk and shell and charcoal is $300/kW OR T$45,000.
- Gasifier accommodation and fuel storage: T$20,000
- Engineering design and installation, including special design and monitoring of fuel combustion system, T$25,000.
- Gasifier plant factor : 80%.
- Gasifier-engine-generator sets load factor : 70%.
- Total Annual generation : 735,840 kWhrs.
- Power use by auxillaries : 5% OR 36,792 kWhrs.
- Gasifier maintenance costs: 3% of capital expenditure annually.
- Gasifier life: 15 years.
- Thermal efficiency of power production of typical loading: 28%.
- Gasifier-related labour : one additional labourer @ $3.50/day for 300 days OR T$1050. Skilled labour requirement is taken as equivalent of one-half time mechanic, allocated at T$1000.
- Diesel power alternative is assumed to have the same plant and load factor.
- Specific fuel consumption is taken as 0,339 litres/kWh diesel, and in dual/fuel operation it is taken as 0.06 litre/kWh diesel and 1.3 Kg husk (assumed to be at 28% m.c.w.b), OR 9.4 ODKg husk (Note: husk is combined with the shell). These data are based on Electricite de Tahiti experience. With Charcoal as the feedstock; 0.54 Kg charcoal/kWh.
- The operating cost of the Vava'u power station at 1981 will be taken to reflect the costs of the diesel engine generator set (See Appendix 6.5.1).

- Fuel costs: Diesel 48¢/litre, charcoal T$120/te (see Appendix 4.1.5(b) for details), husk and shell T$20/te.

  The price of husk/shell is ten times the market price in Tongatapu, and is designed to attract the 'api' holders together and sell good dry husk and shell to the TEPB on Vava'u.

Production costs for each fuel system

1) Gasifier-related — T$/yr

- Capital charges
  Total capex T$157,500 (installed cost) . 15 year life at 10% D.R. — 20,707

- Maintenance: (3% of capex) — 4,725

- Labour — 2,050

  Sub-total — 27,482

  Per kWh produced nett of use by ancillaries related to gasifier feed system — 3.90¢/kWh

2) Fuel costs: Husk and Shell fired — T$/yr

   . Production of 735,840 kWhrs use

   . 1.3 Kg husk/kWh x 735,840 kWh/1000 Kg/te = 957 te

   Thus 957 te husk x T$20/te = T$19.132
   . 0.06 litres/kWh x 735,840 kWh = 44,150 litres

   Thus 44,150 litres x .48$/litre =
   T$21,192 — 40,324

   Sub-total

   Per kWh of electricity produced net of auxilaries 5.78¢/kWh

2 a) Fuel costs: charcoal fired

   . 735,840 kWh x 0.54 kg charcoal = 397 te.
   Thus 397 te x T$120/te = $47,640

   . Diesel as above = $21,192

   $68,832

- Sub-total: per kWh nett of auxilaries — 9.9¢/kWh

2 b) Fuel costs: diesel only

   0.339 kWh/litre x 0.48 $/l = — 16.3¢/kWh

3 Diesel engine-generator

Component

. Capital charges T$800/kW installed for 2 x 150 kW = 300 kW x $800 = $240,000 at 10% D.R. over 15 years	$31,560
. Power station O & M (Appendix 6.5.1) (assume costs will not vary over this range of installed capacity)	$13,200
Sub-total: per kWh	6.1¢/kWh

4 Lubricating oil

. Costed at 5% of diesel fuel based on all diesel fired mode	0.8¢/kWh

Total cost of production at the power house:	c/kWh
. Diesel only (1, 2(b), 3, 4)	27.1
. Diesel - Charcoal dual fuel (1, 2(a), 3, 4)	20.7
. Diesel - Husk dual fuel (1, 2, 3, 4)	16.6

b) New Gasifier Engine Generator Set: 250 kW.

Parameters

- Cost of gasifier engine generator set T$1250/kW CIF Tonga.
- Fuel handling system for 250 kW system $250/kW OR $62,500.
- Gasifier-engine accommodation, civil works T$25,000.
- Engineering design and installation: $25,000
- Gasifier load factor is ideally 70%, though the demand on Vava'u does not prevent this load in the near term. It is assumed that over the life of the plant a load factor of 60% will be achievable. Thus kWhrs generated annually in this simple analysis are 1,051,200. This gasifier system will meet peak demand for the net 5 to 10 years.
- Power use by auxillaries is 5%: 52,560 kWhrs.
- Other parameters as in a) above.

Production cost estimate	Annual cost T$	per kWh produced nett of gasifier auxillaries
1. Gasifier related		
. Capital charges on total capex of T$425,000	$55,888	
. Maintenance: 3% of capex	12,750	
. Labour	$ 2,050	
TOTAL	$70,688	7.08 c/kWh

2. Fuel costs: Husk and Shell-fired	Annual cost (T$)	T¢/kWh
. Husk is 1367 te x T$20/te =	27,331	
. Diesel is 63,072 l x 0.48$/l =	30,274	5.8
2 a) Fuel costs: Charcoal-fired		
Charcoal is 568 te x T$120/te =	68,160	
Diesel is as in 2.	30,274	9.9
2 b) Diesel fueled only		
0.339 litres/kWh and 0.48 T$/l		16.3
3. Diesel-engine generator related		
Capital charges on standby system of 250 kW at T$800/kW	26,300	
Maintenance is provided at 3% of capex	6,000	3.23
4. Lubricating oil costs		0.8

Costs of production at the powerhouse	¢/kWhr
. Diesel only	27.4
. Diesel-charcoal dual fuel	21.0
. Diesel- Husk/shell dual fuel	16.9

Appendix: 4.2.3(b)

GASIFIER RETROFIT AT POPUA POWER STATION; TONGATAPU

Parameters and assumptions

- The typical load pattern of the power system at Popua indicates that for 100% of the time the load is over 800 kW, and more than 90% of the time above 900 kW. The load can be met by one of the two 1198 kW Mirrlees Blackstone 428 r.p.m. machines.

- A gasifier with a plant factor of 80% is assumed to provide the gas energy proportion of 800 kW (minimum load) x 0.8 (plant factor) x 8769 hrs = 5.6GWhrs annually, OR with 3% auxillaries for fuel preparation and handling 5.4 GWhrs nett.

- Gasifier(s) of 1 MW capacity will cost T$350/kW CIF Tonga OR T$350,000.

- Civil works for the gasifier @ T$100/kW capacity : T$100,000.

- Fuel handling (storage, conveying and drying systems only) is T$200/kW of capacity : T$200,000.

- Engineering and installation supervision is $50,000.

- Maintenance is 3% of installed cost: T$21,000 p.a.

- Labour costs: based on 3 labourers for 2 shifts @ $4 manday, T$4380 and an additional mechanic on one shift above the power station staff levels T$2600.

- Specific fuel consumption 1.04 kg husk and shell (20% m.c.w.b.) per kWh at 35% thermal efficiency and 0.045 l diesel per kWh. These high efficiencies are possible as the gasifier and engine system are base-loaded continuously at better then 70% load factor.

- Life of gasifier is 15 years.

- Diesel engine will be regarded as in existence in any case and amortisation charges will not be levied against the gasifier.

- Diesel engine-generation and other power station charges will be included in the cost of the gasifier power system at present day actual cost per kWh produced: 1.1¢/kWh (see Appendix 6.5.1)

- Cost of husk and shell delivered to power station taken as T$10.00/te at 37% m.c.w.b.

Marginal costs of production (T$)	Total annual (T$)	Cost per kWh produced
1. Capital charges on installed cost of $700,000 at 10% D.R., over 15 yrs	92,050	1.64
2. Operations and Maintenance		
a) Maintenance		
. Gasifier-fuel system	21,000	0.38
. Diesel engine-generator and power house ancillaries 61,600	1.06	
b) Fuel: Husk and shell $5.6 \times 10^6 \times 1.04$ kg husk/shell @ $13,20/te as fired	76,877	1.37
. Diesel @ 0.045 l /kWh	112,266	2.00
. Lubricating oil		0.73
c) Labour:	6,980	0.13
TOTAL	287,723	7.31

Breakeven Selling Price on incremental investment in gasifier

Cost	Tongan $
Capital cost	700,000
Annual operation and maintenance	278,723
Annual insurance (0.5% of capex)	3,500

Plant detail	
Installed capacity	1 MW
Annual generation at full capacity	7.0 GWh
Annual generation (lifetime)	5.6 GWh
Capacity load factor (full capacity)	80%
Average capacity load factor 64%	
Economic life	15 years
Regional return post tax	10%

Thus

a) Annual cost per kW installed

. Capital cost (10%, 15 years recovery factor = 0.1315)	92.05
. Operation and maintenance	278.72
. Insurance	3.50
	374.27

b) Break-even selling price

	¢/kWh
. per kWh generated	6.68
. per kWh sold* (6.68 x 1.7/0.86)	9.86

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*Where 1.7 ¢/kWh is administration charges and 0.85 accounts for system losses of 15%.

Appendix: 4.2.3(c)

STEAM-POWER IN TONGA: 1MW AND 2 X 1.5 MW SYSTEMS

a) 1 MW system for baseload operation at Popua Power Station.

Parameters

- A 1 MW steam boiler turbine alternator will play the same role as a 1 MW gasifier (see Appendix 4.2.3.(b). Plant factor will be 80%. Average capacity load factor will be 64%.

- Gross output to loss is 5.6 GWhrs. Net output after 5% use by auxiliaries is 5.3 GWh (Note: hogging and chipping power will only be required for approximately 30% of fuel feedstock - see below. The usual auxillary electricity use of f 10% is adjusted accordingly).

- Fuel taken as husk and shell with moisture output estimated at 37% w.b. and calorific value of 11.6 MJ/kg, upto possible maximum reliable supply of 10,000 te P.A. (see Resource overview for theoretical maximum supply of husk and shell).

- Additional fuel will be coconut logs at 50% m.c.w.b. as received at the boiler. Calorific value is 8.6 MJ/kg.

- Overall efficiency is 12%.

- Fuel costs will be husk an shell @ T$10/te; coconut tree stems @ T$15/te, both delivered to fuelyard.
- Costs of plant: Sea-water cooled, low pressure turbines.

a) Steam-turbine-generator set etc.	T$500/kW	500,000
b) Boilers, furnaces, ancillaries	T$450/kW	450,000
c) Cooling and feed water systems	T$150/kW	150,000
d) Fuel handling and storage	T$250/kW	250,000
e) Civil works incl. buildings, yards, drains etc.	T$150/kW	150,000
f) Engineering (5% of capex)		75,000
		1,575,000

- Life of plant is 20 years

- Maintenance: 3% p.a. on $45,000

- Labour and salaried staff: 4 shift operation

Engineering supervisor 1.	30,000 p.a.
Foreman/mechanic ($8/day) 1.	8,320 p.a.
Semiskilled staff ($5/day) 2.	10,400 p.a.
Labourers ($3/day) 2.	6,240 p.a.
	54,960

Costs of production

		T$/yr	¢/kWh
1)	Capital charges		
.	Discount rate 10%, life 20 years	176,250	3.26
2)	Operations and maintenance		
.	Maintenance	45,000	0.85
.	Labour	54,960	1.04
3)	Fuel		
.	10,000 te husk and shell	100,000	
.	6047 te logs	90,698	3.53
	TOTAL	452,093	8.68

b) 2 x 1.5 MW power station

Parameters

- Firm capacity of 1.5 MW in steam power will cover the demand 70% of the time in the pattern of demand in 1982.

- This firm capacity will supply better than 90% of the energy. Thus, for this calculation of production costs the installed capacity will be assumed to generate 10 GWHrs annually, or roughly 90% of estimated 1983/84 production.

- Auxillaries will consume 8% of power produced leaving 9.2 GWhrs nett production p.a.

- This is an average capacity load factor of only 38%.

- Overall efficiency will be 12%.

- Fuel will be husk and shell up to 10,000 te p.a. or 3.87 GWhrs, and coconut logs for the remainder, or 21,359 te coconut logs to produce 6.13 GWhrs at 287 kWh/te.

- Fuel will cost $10/te husk and shell, and $15/te coconut log.

- Costs of plant: Sea water cooled, low pressure turbines.

a)	Steam turbine generator set	T$400/kW	1,200,000
b)	Boilers, furnaces and auxillaries	T$450/kW	1,350,000
c)	Cooling and feedwater systems	T$150/kW	450,000
d)	Fuel handling and storage	$T200/kW	600,000
e)	Civil works	T$150/kW	450,000
f)	Engineering (5% of capex)		202,500
			4,252,500

- Life of plant: 25 years
- Maintenance: 2% of capex OR $81,000.
- Labour and salaried staff:4 shift operation

Engineering supervisor	1 only	30,000	p.a.
Foreman, mechanic	1 per shift	8,320	
Semiskilled staff	3 per shift	15,600	
Labourers	4 per shift	12,480	
TOTAL		$66,400	

Costs of production	$/p.a.	¢/kWh
1) Capital charges		
. Discount rate is 10%, life is 25 years	446,310	4.85
2) Operations and maintenance		
. Maintenance	81,000	
. Labour	66,400	1.60
3) Fuel		
. 10,000 te husk and shell	100,000	
. 21,359 te logs	320,385	4.57
	1,014,095	11.02

Appendix: 4.4.2

GASIFIER-HOT AIR GENERATOR BOILER RETROFIT AT OIL MILLS IN TONGA

Parameters

- Boiler is 50 HP Trevor Engineering Co. of Melbourne.
- Maximum heat rate 2100 MJ/hr. Operation is 24 hrs/day, 300 days/yr.
- Diesel consumption during production of 5600 te coconut oil in 1981 was about 180,000 litres. This is the assumed 'annual average' consumption.
- Cost of diesel is 47.55¢/litre (May, 1982).
- Gasifier retrofit is taken as Waterwide 70 DF, 2844 MJ/hr firm capacity. Efficiency of heat transfer to boiler and combustion is 85%.
- Cost of gasifier installed is T$15,000 including minor civil works to house gasifier. Maintenance is 3% capex, life 15 years.
- Fuel for gasifier is husk residues from the dessicated coconut factory currently sold at T$2.00/te. The cost delivered to the gasifier at the Oil Mill will be raised to T$10/te consistent with the value allocated for husk as a fuel for power production.
- Fuel value is 11.6 MJ/kg at 37% m.c.w.b. Annual requirement: 690 te.
- Boiler maintenance is assumed to be 3% of capex at T$350/boiler hp. installed OR $525 p.a.
- Labour is required to load a maximum of 180 kg of husk per hour into gasifier. Wholly manual fuel handling is assumed. One labourer for four shifts totalling $3744.

Simple Payback

- Net capital investment is T$15,000.
- Net annual operating costs of gasifier are fuel costs plus non-fuel O & M.
- Annual fuel cost is 690 te husk and shell x 10$/te = $6,500.
- Gasifier O & M is that of gasifier and boiler OR
  (0.03 x $15,000) + $525 = $975.
- Labour is $3744.
- Total annual operating costs are:
  $3744 (labour) + $975 (maintenance) + $6900 (fuel) = $11,619.

- Net annual operating cost of the boiler with diesel is that for fuel only:

  180,000 l x 47.55¢/l = \$85,590.

- <u>Monthly net operating savings of gasifier:</u>

  $$\frac{\$85,590 - \$11,619}{12} = \$6,164$$

<u>Simple Payback</u> = $\frac{\text{T\$15,000}}{\text{T\$ 6,164}}$ = \$6164

Appendix: 4.4.3(a)

GASIFIER-HOT AIR GENERATOR FOR RETROFITTING TO DIESEL-FIRED BAKERIES: TONGATAPU

Parameters

- Bakery model is 'Commodore' from Victor Ewin & Son, Sydney.
- Approximate apportionment of fuel to bakery oven from total use of 1800 litres/week is two-thirds or 1200 litres.
- Cycle for oven usage is 8am-11pm, 7 days/wk.
- Average heat rate is therefore 430 MJ/hr. Peak rate is assumed to be a maximum of double.
- Gasifier retrofit is Brugger Industries type (W. Samoa), estimated to cost \$8000-\$10,000 installed with automatic heat rate adjustment feeding back from temperature using devices in the oven. Heat transfer efficiency, fuel to oven, is 85%.
- Fuel will be coconut husk at 11.6 MJ/kg and costing T\$10/te delivered. (Coconut wood offcuts, scrap timber and charcoal could be used if desirable).
- Maintenance will be 5% p.a. on capex for gasifier.
- Labour will be 1 man at \$4/day and 2 shifts/day, 360 day per year: \$2880.
- Diesel costs 48¢/litre; Annual cost is \$29,950.

Simple payback

- Net capital investment is %10,000 for gasifier only.
- Net annual operating costs of gasifier are fuel and maintenance.
  - Fuel is $\frac{430 \text{ MJ/hr} \times 15 \text{ hrs/day} \times 360 \text{ days}}{0.85 \text{ (efficiency} \times 11{,}600 \text{ MJ/te husk}}$
    = 236 te husk @ \$10/te
    = \$2360 annual fuel cost.

Gasifier O & M is:

Labour \$2880 + maintenance (5% capex) \$500 = \$3380.

Total annual operating costs:

\$3880 (O & M) + \$2360 (fuel) = \$5740.

Annual diesel burner operating costs: taken as fuel only = \$29,950.

Net monthly operating savings of gasifier:

$$\frac{\$29,950 - \$5,740}{12} = \$2018$$

<u>Simple payback</u> $= \dfrac{T\$10,000}{T\$\ 2,018} = 5$ months

Appendix: 4.4.3(b)

BIOGAS FROM COCONUT MILK: TONGA

- Coconut milk is an effluent from the dessicated coconut factory.
- 15 million coconuts p.a., throughput at 1.2 kg/nut, and 25% by weight milk gives 4:5 million litres milk.
- Milk at 3% dry solids, and 0.5 l/gm dry solid, yields 67,500 m^3 biogas at 23 MJ/m^3.
- Biogas system is 90 m^3 capacity (3 m^3 production per unit capacity per day maximum).
- Digestor tanks feed storage and handling, gas cleaning and simple gasometer costs T$300/$m^3$ of capacity T$27,000.
- Net production of gas is 80% of gross, allowing for handling of feed, compression and limited heating to stabilise reaction at 37°C.
- Labour is semiskilled operator/mechanic, $2500 p.a.
- Filling and dispensing station is T$6000 incl. four stage compressor and cylinders.
- Vehicle cylinders and conversion equipment costs T$1500/vehicle for 6 trucks: T$9000.
- Life of cylinders is 10 years, life of production system is 10 years.
- Maintenance is 10% capex.
- Feedstock cost: Nil.

Production costs

a) Capital charges on total installed cost of T$42,000 at 10% D.R. over 10 years	$ 6,833
b) O & M	
. Maintenance (10% capex)	$4,200
. Labour	$2,500
TOTAL	$13,533

. Net production of gas in litres of diesel equivalent : 32,850 litres
OR 41.2¢/litres of diesel equivalent

Appendix: 6.5.1(a)

COST OF ELECTRIC POWER IN TONGA

Capital charges

Estimated present day replacement value of major capital equipment and capital charges:

	1000 T$	Life	Recovery factor (10% dis.rate)	Annual charge
Buildings	420	30	.0902	37,892
Fittings and furniture	10	10	.1490	1,490
Motor vehicles	190	5	.2505	47,587
General plant	3845	15	.1168	449,208
Reticulation	1513	25	.0937	141,736
Distribution & Consumer installations	126	25	.0937	11,806
Other plant, tools & equipment	81	5	.2505	20,291
				710,010

Note: The replacement value of generating plant is taken at $860/kW installed. Reticulation is valued at T$11,000/km for 6.6 kV/11 kV reticulation and T$5000 for distribution at 415 Volts. Buildings and fittings, motor vehicles and other plant are somewhat undervalued, being assigned at close to book value supplied by TEPB. Present day replacement values for these items could not be established during the period of the mission. Hence capital charges are, to that extent, underestimated.

Estimated Sales for 1982/83

Assume sales will remain at approximate level of April-May 1982

Capital charges per unit sold: 8.45 cents/kWh.

Fuel costs

- Diesel fuel was sold to TEPB in Tongatapu as of 1 July 1982 for 43.00¢/litre.
- At 43.00¢/litre, 34% thermal efficiency and 14% losses the fuel cost is 14.01¢/kWh sold.
- Lubricating oils average 5% of the value of fuel per kWh sold: 0.70¢/kWh.
- Total fuel cost at mid-1982: 14.71¢/kWh.

Maintenance Costs

- Expenditure was close to budget for the 1981/82 financial year (July/June) when records were inspected in March/April. Hence the budget for maintenance is accepted as an estimate of maintenance charges and 5% is added to reflect costs for inflation. Physical plant was in good condition and routine maintenance was up to date.

- Due to the cyclone of February 1982 there has been extensive damage to reticulation. While there has been considerable aid assistance in repair the burden of unplanned maintenance will distort maintenance costs from March for the next 12-18 months. If this is not to be covered entirely by aid some recovery will have to be made in tariffs.

Maintenance budget	T$'000	Cost per unit sold
Power house generator	108	1.33
Transmission/distribution	53	0.65
Other services and stores	45	0.56
Transport	48	0.59
Stores purchases	161	1.99
		5.12

Administrative overheads:

Budget figure T$140,000 plus 5% is $147,000 OR 1.82¢/kWh

Other revenue

Sales of goods and services: T$305,000 (est) or 3.76¢/kWh.

Total operation and maintenance charges

	¢/kWh sold
Fuel and oil	14.71
Maintenance	5.12
Administration	1.82
	21.65
Less value of other revenue from operations	3.76
Net cost	17.89

<u>Total cost of supply</u> allowing for a 10% return on funds employed.

	¢/kWh
Capital charges	8.45
Operations and maintenance (net)	17.89
	26.34

Appendix: 6.5.1(b)

COST OF ELECTRIC POWER IN VAVA'U

Capital charges

Estimated present day value of capital equipment and annual capital charges

	T$'000	Life	Recovery factor (10% dis.rate)	Annual charge
Generating plant	450	10*	.1490	67,043
Reticulation	359	30	.0902	32,382
Buildings	14	25	.0937	1,312
Vehicles	20	5	.2505	5,010
				105,767

- Annual sales estimate, 1982: 720,000 kWhrs. Assumed to remain at level of March-May 1982.

- Capital charges are 14.69¢/kWh.

Fuel costs

- The cost of diesel to the TEPB on Vava'u was 46.45¢/litre in mid-1982.

- Overall efficiency is 26%.

- Lubricating oils are 5% of fuel costs.

- Total losses average 18%

*High speed diesels are nominated a 10 year life.

Total fuel cost per unit sold: 21.79¢/kWh.

Operations and maintenance (est. = 81/82 budget plus 5%)

	'000 T$
Power station and plant	13.9
Transmission and distribution	10.7
Transportation	2.3
Administration	5.3
Equipment and stores	15.4
	47.6
Total O & M per unit sold	6.61¢/kWh
Other revenue (electrical sales & service):	$21,700
per kWh sold:	3.01¢/kWh
Total net non-fuel operating costs :	3.60¢/kWh

Total cost per kWh sold:

Capital charges	14.69
Fuel costs	21.79
O & M costs (net)	3.60
	40.08

Annex 15

Appendix: 6.5.1(c)

TONGA ELECTRIC POWER BOARD SYSTEM COST BETWEEN TONGATAPU AND VAVA'U

Based on projected 1981/82 sales in the absence of cyclone Isaac, the cost of supply averaged between Tongatapu and Vava'u is 27.6¢/kWh.

Appendix: 6.5.4

ELECTRICITY TARIFF REVISION: BACKGROUND DATA

A revised tariff

- Key objectives:

  (1) The normal rate per unit should be approximately equal to the system's marginal cost of supply.

  (2) Provide domestic consumers with a small amount of power adequate for basic services at below the full cost of supply (the 'lifeline' block).

- Tariff structure:

First 50 units	15¢/kWh
Remainder	28¢/kWh
Minimum charge	$2/month

In principle the 'lifeline' block should apply only to domestic (and perhaps small commercial) consumers. For ease of administration it is probably preferable to have it apply to all consumers; the effect of this on revenues is slight.

In this analysis we assume that the same tariff will apply throughout Tonga, which in effect means that Tongatapu consumers subsidize those on the other islands. At present, the estimated cost of supply per unit is about 50% higher on Vava'u than on Tongatapu (see Appendix 6.5.1).

Effect on consumers

The following table is based on the mission's analysis of electricity sales for February 1982 on Tongatapu and November 1981 for Vava'u.

	Consumption per month (kWh)			
	0-11	12-50	51-525	Over 525
% of consumers	19	43	36	3
Average bill ($)				
- present	2.15	5.07	24.76	557.
- proposed	2.00	3.98	29.79	814.

Note: The average bill is based on the average monthly consumption within each class, and is a weighted average between Tongatapu and Vava'u. Under the proposed tariff all consumers using less than 75 kWh/month will have an average bill below that resulting from the present tariff. This includes probably almost 70% of all consumers.

Effect on revenue

Accurate assessment of the effect of the proposed tariff on revenues is difficult, since the substantial increase in tariff for large consumers may lead to a reduction in consumption. Consumers who would receive a large tariff increase (say, over 30%) include only those using over 200 kWh/month; these account for a small (10-15%) percentage of consumers. They are responsible for a large share of sales, however (75-85%). To allow for possible changes in demand due to the price increase, the effect of the proposed tariff is calculated for different scenarios of reduction in total sales. All units "unsold" due to lower consumption are assumed to incur for everyone revenue of 28¢/kWh. The change in net revenue assumes that 100% of the fuel cost and 50% of the operations and maintenance cost are saved for each "unsold" unit (see Appendix 6.5.1).

Revenue from the proposed tariff in 1982/83 is estimated based on average monthly consumption as follows:

Consumer class	No. of consumers	Total units	Revenue (T$)
Minimum charge	1100	6,600	2,200
12-50 kWh/month	2500	65,000	9,750
51-525 kWh/month	2150	279,500	64,285
Over 525 kWh/month	175	385,000	106,665
TOTAL	5925	736,100	182,900

Note: (1) The average consumption in each class is based on February 1982 (Tongatapu) and November 1981 (Vava'u) sales data, with modification for estimated changes in 1982/83. The greatest uncertainty is with the over 525 kWh/month class: the average used here (2200 kWh) is estimated to make total sales match with the pattern of April-May 1982.

(2) Number of consumers assumes modest growth over the existing level.

(3) Sales in Ha'apai are not included. The effect would in any case be small.

Annual revenue based on the above is T$2.19 milion. Direct costs to supply the above power are estimated as T$1.65 million (based on Appendix 6.5.1). Adding capital charges of T$0.82 million gives a total cost (including return on capital) of T$2.47 million. The shortfall in revenues of T$280,000 is the size of the subsidy to sustain the lifeline block. Assuming the same sales pattern as above, revenue from the present tariff in 1982/83 would be only T$1.65 million, with a shortfall of T$920,000. Annual net revenue (i.e. revenue minus the cost savings from not having to generate a certain number of units).

Scenarios of demand reduction would be as follows:

Demand reduction	Annual net revenue
none	T$2.19 million
5%	2.15 million
10%	2.11 million

Appendix: 8.2.2

STRUCTURE AND DUTY STATEMENT FOR THE EPU

1. Energy Planner and Head of Energy Planning Unit.

Background: Economist, analyst, preferably with some technical scientific training and experience in management/administration.

Duties:

- Administrative/executive secretary to the NEC.
- Project analysis.
- Advice on pricing of energy products and elasticities of demand.
- Establish the sensitivity of energy costs to production of goods and services.
- Advise on appropriate taxes, duties and levies for energy technologies, industrial conversions.
- Establish and monitor indices in the energy-economy relationship.
- Develop and maintain comprehensive statistics of the energy sector.

2. Planning Engineer

Background:

Mechanical/electrical engineer with experience in planning and decision-making techniques.

Duties:

- Advise implementing agencies of technical options.
- Undertake preliminary design and costing for fuel production, conversion and end-use appliances.
- Monitor and report technical performance of pilot projects.
- Advise and inform government and private sector on technological choices in the energy sector.
- Review power system planning and development.

3. Biomass fuels planner

Background:

Biological scientist with background in biomass production and handling systems (e.g. agriculturalist, forester).

Duties:

- Co-ordinate and undertake biomass fuel resource inventories.
- Design and cost integrated systems of energy, food and timber production.
- Advise on all the conversion of biomass fuels to usable energy forms.
- Advise and inform government and the private sector on opportunities for biomass fuel production and conversion.
- Monitor and report on programmes of biomass harvesting production.

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