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Wood-fired Cogeneration for Rural Pacific Communities: A Taveuni Case Study

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WOOD-FIRED COGENERATION FOR RURAL PACIFIC COMMUNITIES:

TAVEUNI CASE STUDY

A Special Report

by

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June 1984

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ACKNOWLEDGMENTS

The present study is the result of five days of field work conducted in Taveuni and Suva, Fiji, in December 1983. I wish to thank the following persons for making my short stay both pleasant and efficient: Mr. A. R. Tarte of the Wainiyaku Plantation, his assistant, Koya, and the estate's able and hospitable chief of maintenance, Robin Powell. Thanks also to Messrs. H. Wade and K. Conger of the Fiji Ministry of Energy and Mineral Resources and P. Johnston of the U.N. Pacific Energy Development Program. Finally, I wish to acknowledge the support, guidance and editorial assistance of M. Hammett and S. Pintz of PIDP/RSI at the East-West Center.

A Note About Units of Measurement

The steam engine was invented in the late 1700s, well before the principles of the science of thermodynamics were understood. In fact, it can be truthfully said that steam engines did more for thermodynamics than thermodynamics did for steam engines.

The first application for the steam engine was as a water lifter in English coal mines. The further development of this venerable technology was primarily a British endeavor, and tradition and the literature describe the steam engine in English units of measurement. In this paper, references will be variously made in both English and Metric (S.I.) units in deference to steam power's long lineage and to metric-accustomed readers.

WOOD-FIRED COGENERATION FOR RURAL PACIFIC COMMUNITIES: TAVEUNI CASE STUDY

INTRODUCTION

The Wainiyaku plantation occupies some 2,000 acres on the southwest extremity of Taveuni, third largest island of the Fiji group located approximately 250 kilometers from the port of Suva. The plantation is privately held by a European-Fijian family whose residence dates back to the late 1800s. The principal plantation outputs are copra and beef, with the production of the former equal to 400 tonnes (441 short tons) of 100 percent Grade 1 copra annually from approximately 800 hectares under coconut. An additional 400 tonnes per year of copra is dried at Wainiyaku through contractual arrangement with other Taveuni estate owners. Cattle range under coconut palms and are processed at the on-site butchery which is equipped with freezer storage facilities. Other plantation infrastructure includes a garage equipped with power tools, a plantation office, and the manager's residence. The plantation employs twenty-eight laborers who are quartered, along with their families (estimated 200 persons), on the estate.

Previous to 1979 the Wainiyaku estate was entirely dependent on diesel oil for its electrical and copra drying needs. Electricity generation was accomplished through a 30 kVA diesel generator, while the copra throughput was dried in two diesel-fired forced draft (ASP/Chula type) units. Total diesel consumption for the electricity generation and copra drying functions was approximately 5 Imperial gallons/hour (22.7 l/hr) (U.S.$70,000/year at current prices; FID 1.00 = USD1.00 current exchange rate). Anticipating a rise in oil prices, the estate owner/manager began planning for a wood-fired cogeneration system in 1977.

A heat engine has fundamental thermodynamic limitations on the amount of heat energy from the burning fuel that can be converted to electricity. For example, in the present generation of large-scale fossil fuel-fired power plants only 35 to 40 percent of the fuel energy ends up as electricity. The remaining 60 to 65 percent of the energy is rejected in the form of low-temperature waste heat. This heat serves no useful purpose in conventional systems yet it must be paid for by the electricity consumer in order to get the electricity. The logical step is to make some use of

the waste heat coming out of the power plant. This idea of cogeneration of both heat and electricity immediately increases the overall efficiency and economic viability of the system. The key challenges for a cogeneration system planner are:

1. Find an economic end use for the low grade heat output; and
2. Properly match the magnitude of end use demands for electricity and heat to the relative and absolute amounts of electricity and heat produced by the power plant; the relative amounts are a function of the energy conversion technology employed, while the absolute quantities are a consequence of plant sizing.

A cogeneration system loses many of its advantages if the fuel for it becomes unavailable or prohibitively expensive. A locally available renewable fuel provides a more stable economic base for the payback of the capital cost for cogeneration equipment. Such a fuel is available in many parts of the Pacific, including Wainiyaku, in the form of wood and agricultural waste. The attributes of wood as a fuel are given by Fraser:

1. Renewable if harvested on a sustained yield basis;
2. Supply and price are potentially more stable than fossil fuels;
3. Convertible to other forms such as heat, gas or electricity;
4. Production and harvesting systems can be low cost and small-scale;
5. Contains negligible sulphur;
6. Ash content is low and can be recycled as a fertilizer;
7. Often available as a waste product.

Not to be ignored are the problems associated with wood fuel. It is bulky, so it requires large storage areas and can involve significant transportation costs. Automated wood fuel handling systems (necessary in all but small-scale installations) are expensive. Its moisture content affects the energy content per unit weight.

Wood can be converted for use by several methods:

1. Direct Combustion. Burned with excess air in a boiler or an air-heating combustor.
2. Gasification. Partially combusted in the presence of steam or air to produce a gaseous fuel (a mixture of carbon monoxide and hydrogen gas) with a heat content of about 15-30 percent that of natural gas. Can be used with existing natural gas boilers with

modifications of burner jets. Moisture content is sometimes a problem.

3. Pyrolysis. Material is heated in an anaerobic (oxygen depleted) environment. It does not burn, but breaks down into gaseous, liquid, and solid fractions, all of which are fuels. Charcoal is made by pyrolysis.
4. Anaerobic Digestion. Material is broken down by anaerobic bacteria at low temperatures to produce methane gas and a sludge that can be used for fertilizer. Very low yield using wood fiber.
5. Fermentation. Material first is broken down by solvent, enzyme or acid hydrolysis into simple sugars, and then is fermented by yeasts into ethanol, a liquid fuel.

All these processes are technically feasible, but differ in their degree of commercialization and efficiency of conversion. Direct combustion is the simplest process and has a reasonable efficiency, high reliability and ease of operation, and a wide range of proven equipment to choose from. While direct wood combustion can be applied in a system where a gas (e.g. air) is the working fluid (e.g. Stirling cycle), it is usually used to raise steam (Rankine cycle) for reasons of familiarity and cost.

Given the previously stated criteria, conditions at the Wainiyaku plantation can be seen to be highly favorable towards the application of wood-fired cogeneration. There is an on-site low-cost source of wood fuel in the form of waste coconut husk and shell, a byproduct of copra-making. An economic end use of waste heat, copra drying, is well established. There is a high demand for heat energy relative to electrical output, thus making the fuel to electrical energy conversion efficiency a non-critical factor.

The major remaining technological choice for the Wainiyaku application concerned the method of converting the thermal energy contained in the steam to mechanical energy (and then to electricity through the usual generator set). In medium to large-scale power generation installations, steam turbines predominate because of higher overall system efficiencies attainable and lower capital costs. However, in small-scale rural applications reciprocating piston steam engines become competitive because of the following considerations:

1. Steam engines are less likely to fail suddenly or catastrophically than turbines, and the reciprocating cycle is analogous to the familiar diesel or gasoline engine;
2. The low-grade waste heat expelled by steam engines is suitable for agricultural processing; the turbine expelled higher-grade process heat often desired in industrial applications is not required;
3. Steam engines exhibit a relatively constant steam rate characteristic over a range of loads; steam turbine efficiency drops rapidly when operated at less than optimum;
4. The light weight and compact design advantages of steam turbines are not normally highly valued in most intended rural applications;
5. The capital surcharge for steam engines over steam turbines at this scale is small when factored over the expected system lifespan.

A wood-fired cogenerating steam power system was thus selected and commissioned in April 1979. Total operating experience with the presently installed steam engines is three years at this writing. It should be noted that the system was originally turbine-based, but operations and maintenance difficulties (principally turbine main bearing failure) led the owner to switch to a reciprocating engine.

WAINIYAKU PLANTATION SYSTEM

SYSTEM DESCRIPTION

Please refer to Figure 1, System Schematic Diagram.

For descriptive convenience, the cogenerator is broken down into the following components:

Fuel Dryer/Storage. Wet coconut husk/shell is transported by tractor from the copra-making area. A portion of the heat exchanger warm air output is drawn off to heat a small husk/shell dryer; in practice the volume of warm air delivered is inadequate to make a sufficient difference in fuel drying rate. It has been suggested that an alternative source of heat for fuel drying would be recovery from flue gas through a heat exchanger on the stack. This modification would have to be studied carefully due to a possibility of condensation in the stack which would lower boiler efficiency. Therefore, for the present the system consumes husk/shell which is primarily dried by natural circulation of ambient air. If the husk/shell arrives particularly wet and does not dry to a sufficient

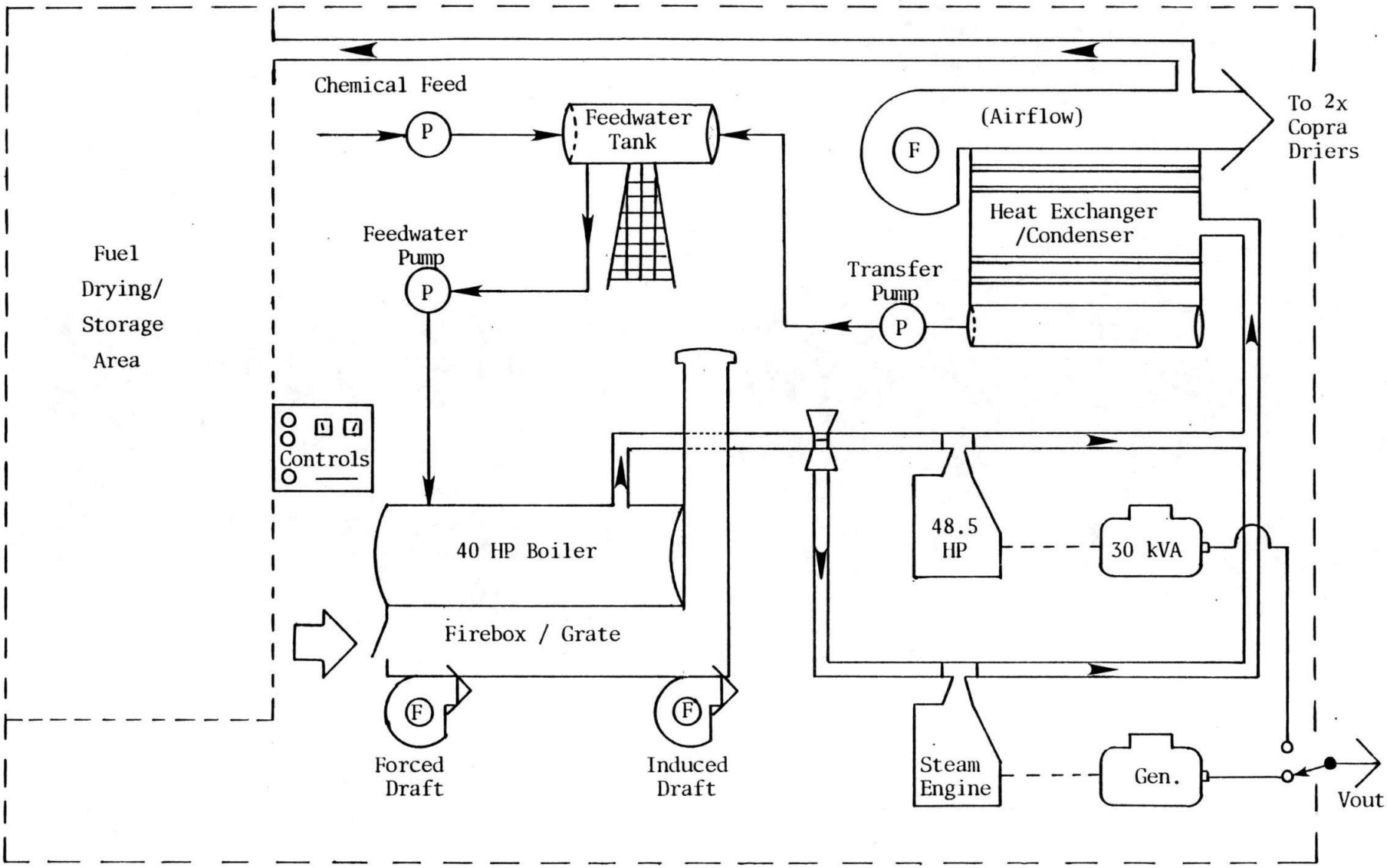


FIGURE 1. SYSTEM SCHEMATIC DIAGRAM
Steam Generator / Copra Dryer
Wainiyaku Plantation

level, it is partially substituted for by coconut wood billets which are available on the plantation.

Control Box. Gives a visual display of system status and provides an audio/visual alarm should boiler water level reach unsafe low levels.

Feedwater Treatment System. Consists of a chemical reservoir, timer and pump which feed hydrazine (an oxygen scavenger to prevent corrosion) and "chemical O" (for PH balance and scale inhibition) to the boiler feedwater tank. The type and amounts of chemicals to be added are determined by laboratory analysis and depend on source water PH, mineral content and dissolved oxygen, and boiler type. Typical boilers require a feedwater alkalinity of PH 8-10 for minimum corrosion. Also, feedwater sources high in particulates may require addition of a flocculant.

Feedwater System. Includes a transfer pump which lifts the condenser tank output to the elevated 80-gallon feedwater tank. Water from the tank is introduced into the pressurized boiler by means of the feedwater pump. Water source is a roof catchment which empties into an underground reservoir tank.

Firebox/Boiler. The boiler is of the single-pass firetube type, manually fed 24 hours/day by 3 shift x 1 stoker/fireman. Combustion is aided by one forced draft and one induced draft fan. The manufacturer, Anderson of Christchurch, New Zealand, rates the boiler at 40 boiler horsepower (392kW) (one boiler horsepower is a somewhat antiquated term meaning the ability to raise 34.5 pounds of steam from and at 212°F). Maximum output is rated at 1700 lbs/hour (771 kg/hr).

Steam Engine and Generator. The Wainiyaku set-up employs dual engine generator sets with only one operating at a time. The redundancy minimizes down time but is not required in typical applications. The engine is of the counterflow double-acting, single-expansion type and is mechanically governed. Skinner of Erie, Pennsylvania rates it at 48.5 brake horsepower (36.2 kW). The vertical single-cylinder engine is slightly overmatched to the 30 kVA rated generator made by Newage of England. (It is capable of operating a 37.5kVA generator.) The generator is linked by belt drive and puts out 3-phase 415V - 240V AC, electrically load regulated with 80 percent power factor.

Heat Exchanger/Condenser. This component transfers the heat energy of

the engine exhaust wet steam to the airflow across the exchanger surface. A bypass valve allows boiler steam to enter directly if the engine is not operating. Airflow is provided by a 7 HP (5.2 kW) blower rated at 20,000 cfm (566 m^3/min). The copra driers are equipped with a thermostatically controlled gate which admits ambient air so as to maintain heated air temperature at the optimum 165°F (74°C) for copra drying. Cylinder lubricating oil injected at the steam engine is separated from the condensate output of the heat exchanger so as to prevent boiler foaming. The condensed water collects in a small tank which feeds the transfer pump for circulation.

TYPICAL OPERATING PARAMETERS

Typical operating parameters are given in the following Appendices:

Appendix I - Input-Output Analysis
Appendix II - Electrical Load Analysis
Appendix III - Copra Drying Load Analysis
Appendix IV - System Energy Flow Analysis
Appendix V - Fuelwood Drying/Storage Analysis

Main results are summarized below:

- The plant typically operates at about 70 percent capacity with respect to electrical output and amount of steam raised.
- Net electrical efficiency is approximately 6 percent.
- Electrical load factor exceeds 80 percent.
- Total system efficiency {(net electrical output + heat recovery) divided by energy value of fuel input} is approximately 50 percent.
- At typical levels of operation and throughput the heat supplied to the driers is well matched to the heat load for copra drying.
- Fuel consumption is 5.7 kg (12.6 lb.) air-dried husk + shell/kWh.
- Land area under coconut required is approximately 500 hectares, or slightly more than half the husk + shell output of the plantation.
- Fuel drying requirements are husk and shell dried to no more than 40 percent m.c.w.b. Estimated storage area is 100 m^2.
- Makeup water requirements are 10 Imperial gallons/day (45.5 l/day) treated with 8 ml hydrazine (0.27 oz).

POLLUTION CONSIDERATIONS

Air Pollution

In complete wood combustion at high temperatures little visible smoke is emitted. The following table gives estimated air emissions for conventional wood combustors (figures are scaled for the Wainiyaku wood consumption rate of 2.0 air-dried te/day).

Air Emissions

	U.S. EPA Estimates Conventional Wood Combustors	U.S. EPA Standards New Solid-Fuel Power Plants
Particulates	205 - 625 g/hr	45 g/hr
Sulphur Oxides	110 g/hr	575 g/hr
Carbon Monoxide	85 -2500 g/hr	—
Hydrocarbons	85 -2915 g/hr	—
NO_x	415 g/hr	340 g/hr

The pollutant of main concern is particulate emissions. According to EPA, "well-designed" wood combustors fall in the low end of the 205-605 g/hr range. This level does not meet U.S. standards for large scale solid-fuel power plants (i.e. coal-fired), but is within acceptable limits when compared with Great Britain standards for boiler furnace particulate emissions of 275 - 1,025 g/hr.

Water vapor exiting from the stack will condense into microscopic droplets, forming visible clouds. This water vapor plume should have negligible effect on the surrounding area.

Noise Pollution

An external combustion engine, such as a steam engine, is inherently much quieter than a diesel engine of equivalent scale. Normal conversation is possible within an arm's length of the steam engine. Noise pollution effects are thus judged to be insignificant.

OPERATIONS AND MAINTENANCE CONSIDERATIONS

Maintenance Schedule

Procedure No.	Frequency	Downtime	Description
1.	Daily	-	Check feedwater levels.
2.	Daily	-	Check feedwater chemical levels.
3.	Daily	-	Check cylinder lubricator oil level.
4.	Weekly	2 hours	Clean boiler tubes with brush and clean ash from under firebox grate.
5.	6 months	1 hour	Adjust/tighten crosshead and pins.
6.	6 months	1 hour	Change crankcase oil.
7.	Yearly	1 hour	Check main bearing shims. Check piston rings for wear and carbon deposit.
8.	Yearly	3 hours	Change steam packing.
9.	Yearly	2 hours	Boiler safety inspection.

O & M Personnel

In general, the operation and maintenance of a boiler/engine system of the Wainiyaku scale requires the following types of personnel:

	Title	Duty Cycle	Skill/Training	Function
1.	Stoker/Fireman	Continuous in 3 shifts	Unskilled	Feeds fire; assists procedures 1-4.
2.	Operator/Attendant	20% time	Basic mechanical + OJT	Monitors control settings; oversees/ performs procedures 1-4.
3.	Mechanic	6 month intervals	Diesel or marine propulsion experience	Performs procedures 5-8.
4.	Boiler Inspector	Yearly visit	Employed by PWD, Suva	Performs procedure 9.

Steam system maintenance can be seen as more frequent but less complicated and less critical than diesel generator maintenance.

System Lifespan

As a rule, slow-speed reciprocating machinery exhibit longer lifespans than high rpm engines; only large diesel sets are comparable to the steam engine with respect to low rpm and piston speeds. A steam engine does not have to withstand high temperature, corrosive combustion gases; all combustion processes are contained in the boiler furnace. Also, there are no explosive ignition detonations with resulting pressure shocks to cylinder assemblies and running gear. In sum, steam engines are robust devices, normally capable of taking all the steam that can be supplied by the associated boiler. Marine steam engines commonly operate for 25 to 30 years before general overhaul.

Boilers are essentially static devices with no moving parts. The main afflictions, corrosion and scale, should be controllable with proper feedwater treatment.

Assuming performance of the indicated maintenance, a system lifespan of 25 years is not overly optimistic and has been adopted for the following financial analysis.

FINANCIAL ANALYSIS

Key assumptions and cost data for a financial analysis of the Wainiyaku system are contained in Appendix VI. Results of net present value analyses as obtained from the microcomputer are summarized in Table 1, overleaf. Interested readers may also refer to a related paper (Gowen, 1984) for a description of the COMPRAN project analysis microcomputer program.

Just a cursory look at Table 1 reveals that the plantation scale cogeneration system was a highly favorable investment. Even in the "worst case" scenario, the project shows a Net Present Value of $105,777 and a B-C/K ratio of 2.19. (The latter ratio, incidentally, is the only commonly computed decision criterion which can be used to rank independent projects requiring dissimilar levels of capital outlay.) At this point, one may

argue that the plantation really has no economic use for all the electricity the system produces, or that the use of the electricity is subject to diminishing returns. In response, note that the plantation owner ran an equivalent-sized diesel set 24 hours/day in pre-cogeneration times at an equivalent fuel only cost of 15.6¢/kWh. Therefore, this fuel replacement value is a logical and conservative take-off point. Indeed, given the copra drying benefit, the "bonus" electricity could be worth only 5-7 ¢/kWh for the investor to break even.

TABLE 1. Results of Net Present Value Analyses
Plantation Scale Cogeneration System
Financial Analysis

(NB: FID 1.00 = USD 1.00)

Scenario	NPV	B/C	B-C/K
1. D.R. = 5% FEA Viti Levu tariff electricity	$200,579	1.72	3.25
2. D.R. = 5% Estimated diesel full marginal cost electricity valuation	545,358	2.96	6.65
3. D.R. = 10% FEA Viti Levu tariff electricity valuation	105,777	1.52	2.19
4. D.R. = 10% Estimated diesel full marginal cost electricity valuation	327,827	2.62	4.49

Breakeven electricity valuation:

@ 5% D.R. = 5 ¢/kWh
@ 10% D.R. = 7 ¢/kWh

The attractiveness of the conversion from a diesel to a wood-fired system was due, in the greater part, to the following factors:

- o High utilization of the electrical generating capacity of the plant. Operation is nearly continuous, with load factors exceeding 80 percent. Capacity factor (defined as average load divided by maximum rated output) is approximately 70 percent.

- o High utilization of the copra drying capacity of the plant. The plantation's own output of 400 tonnes of copra per year is large, and through contractual arrangement an additional 400 tonnes/year is dried at Wainiyaku. At typical levels of operation, about all of the recoverable waste heat is put to economic use.

- o Low fuel cost as coconut husk and shell with assumed zero opportunity cost are available on-site.

EXTENSION TO 10KW VILLAGE-LEVEL SYSTEMS

OPEN VS. CLOSED LOOP SYSTEMS

In this section the viability of installation of scaled-down versions of the Wainiyaku plant in rural village environments is examined. In order to compare relative advantages, and because not all villages produce copra or some other agricultural product that requires drying, two different types of systems were reviewed.

Closed Loop

This system is of the Wainiyaku type, in which output wet steam from the steam engine is condensed in a heat exchanger and the resulting water recirculated back to the boiler. For purposes of the analysis, the setting was a copra-producing village with 500 hectares under coconut and a yearly output of 140 tonnes of dried copra. Copra-drying methods formerly employed were assumed to be solar, or wood-fired kilns. It was further assumed that the steam plant operates 325 days/year, 16 hours/day at 40 percent load factor.

Open Loop

In this variant exhaust wet steam is not cycled through a heat exchanger; crop drying using waste heat is not possible. However, hot water is available as an output and may be used for washing, bathing or other purposes. Because the feedwater is not circulated, the plant must be sited next to a water source such as a stream. With a typical water rate of 75 lbs/kWh (34 kg/kWh), at peak output a 10 kW/system would require 750 lbs/hr, or approximately 75 Imperial gallons of water per hour (341 l/hr). Feedwater treatment may be required; even if the stream water is of the proper alkalinity it will initially be high in dissolved oxygen. Also, open loop systems will normally be of somewhat lower efficiency than recirculating systems due to the lower temperature of entering feedwater. These last two considerations should be the subject of further investigation.

Fuel was taken to be wood wastes at $10/te. Three operational patterns were examined: 6 hours/day, 12 hours/day, and 24 hours/day, all for 360 days/year at 80% load factor.

FINANCIAL ANALYSIS

Closed Loop System

Financial analysis details may be found in Appendix VII, and results of net present value analyses as obtained from the microcomputer are summarized in Table 2, overleaf.

In comparison with the Wainiyaku cogeneration installation, this village-level system exhibits:

- Poor (negative) economies of scale due to high capital costs in the boiler/furnace, feedwater system and hot air system.

- Lower levels of utilization of the electrical generating capacity of the plant; with operation 325 days/year, 16 hr/day at 40 percent load factor, the effective load factor is 24 percent.

- Lower levels of copra throughput and lack of access to further copra supplies to be dried under contract; therefore a lower proportion of recovered waste heat is utilized.

Table 2. Results of Net Present Value Analyses
Village Scale Closed Loop System
Financial Analysis
(NB: FID 1.00 = USD 1.00)

Scenario	NPV	B/C	B-C/K
1. D.R. = 5%	$1,268	1.01	1.18
2. D.R. = 10%	-12,069	0.89	0.80

Breakeven electricity valuation:

@ 5% D.R. = 50¢/kWh
@ 10% D.R. = 58¢/kWh

ECONOMIC ANALYSIS

Open Loop System

Economic analysis assumptions and shadow pricing may be found in Appendix VII, and results of net present value analyses are given in Table 3, overleaf.

As to be expected of an energy production project with relatively high capital cost and low fuel costs, utilization of the electricity is the key variable in determining the project's economic viability (social discount factor would also have a large effect, but its rules for determination are such that choice is often made by rule of thumb: say 10-12%). Providing nighttime lighting is certainly an effective rural electricity utilization, but is typically limited to 4 to 5 hours/day. If there is little or no potential productive use for additional electricity, such as refrigeration or power tools (that is, the marginal benefit is small), then it makes little sense to invest in a steam engine-generator which only begins to look attractive relative to diesel when operated upwards of about 8

hours/day. If, however, as World Bank asserts, rural electrification benefits tend to be intangible and also grow over time, then perhaps one can justify installing a high capacity, high marginal cost "baseload" type technology in a rural village. This is where the value of social cost/benefit studies of rural electrification can be demonstrated.

Even where utilization levels are not expected to be particularly high, a rural 10kW project may be favored based on criteria of petroleum independence, availability and opportunity cost of external funding, reliability, and employment creation.

Table 3. Results of Net Present Value Analyses
Village Scale Open Loop System
Economic Analysis (D.R. = 10%)
(NB: FID 1.00 = USD 1.00)

Scenario	NPV ($)	EIRR (%)	B/C	B-C/K	Break-even price (¢/kWh)
1. Operation 6 hr/day; 0%/yr electricity value inflation	-8,249	8	0.89	0.83	53
2. Operation 12 hr/day; 0%/yr electricity value inflation	44,280	23	1.50	1.90	37
3. Operation 24 hr/day; 0%/yr electricity value inflation	149,338	68	2.27	4.05	-
4. Operation 6 hr/day; 2%/yr electricity value inflation	4,547	11	1.06	1.09	49
5. Operation 12 hr/day; 2% yr electricity value inflation	69,872	27	1.79	2.43	29
6. Operation 24 hr/day; 2% yr. electricity value inflation	200,521	75	2.71	5.09	-

CONCLUSIONS

It was postulated in the introduction to this paper that the conditions existing at the Wainiyaku plantation were favorable to the application of wood-fired cogeneration for reasons of proper matching of electrical and heat outputs to end-use demands and low fuel costs. Indeed, the results suggest that wood-fired cogeneration based on a steam engine is an attractive proposition for similar scale plantation agriculture in general.

At the 10kW village level, we cannot be so sanguine about cogeneration. Dis-economies of scale loom in importance, and the high relative capital costs of outfitting a steam engine generator so that it may also perform crop drying are such that it will probably be an attractive investment only for villages having an unusually large or valuable agricultural product to process.

Open loop steam engine/generator sets at the 10kW village scale may be a favorable development if electrical utilization will be higher than is customary in village environments or if equipment costs drop. Projected generation costs of approximately 29 to 53 ¢/kWh (depending on load factor) should be compared to real costs for rural diesel and other rural electrification alternatives. Additionally, evaluations based on broader criteria than strict economic analysis may favor steam engine-based power generation at this level.

REFERENCES

Bene, J. G., H. W. Beall and H. B. Marshall (1979). Energy from Biomass for Developing Countries, IDRC, Ottawa.

Benemann, John (1978). Biofuels: A Survey, ER-746-SR, Electric Power Research Institute, Palo Alto, California.

Brookfield, H. C. et al. (1977). "Population, Resources and Development in the Eastern Islands of Fiji: Information for Decision-Making," Man in the Biosphere series, UNESCO/UNFPA.

Brookfield, H. C. et al. (1978). "Taveuni," Man in the Biosphere series, UNESCO/UNFPA.

Fraser, A. I. (1980). "Wood as a Source of Energy for Rural and Island Communities," in Energy for Rural and Island Communities, Ed. J. Tidwell, Pergamon, Oxford.

Fraser, A. I. (1981). "The Use of Wood For Industrial and Domestic Energy in Rural Areas of Britain and the Transfer of Wood-Energy Technology to Developing Countries," in Energy for Rural and Island Communities, Ed. J. Tidwell, Pergamon, Oxford.

French, David (1979). "The Economics of Renewable Energy Systems for Developing Countries," USAID, Washington, D.C.

Government of Fiji (1980). Fiji's Eighth Development Plan 1981-1985, Central Planning Office, Suva.

Gowen, M., and C. Feinstein (1984). "COMPRAN: A Microcomputer Tool for Project Analysis," Resource Systems Institute, East-West Center, Honolulu.

Johnston, Peter (1977). "Use of Wood Waste for Rural Electrification," Central Planning Office, Suva.

Newcombe, Ken et al. (1982). "Pacific Energy Programme Mission Report/Fiji/Kiribati/Solomon Islands," PIDP/RSI, East-West Center, Honolulu.

Siwatibau, Suliana (1981). Rural Energy in Fiji: A Survey of Domestic Rural Energy Use and Potential, IDRC-157e, IDRC, Ottawa.

Stayton, Robert (1980). "Wood Fired Cogeneration For University of California, Santa Cruz," Final Report under Grant No. EM-78-G-03-1937, U.S. Department of Energy Pacific Southwet Region IX, San Francisco.

Stern, Cecil (1977). Air Pollution, 3rd Edition, Vol 5, "Air Quality Managment," Academic Press, New York.

U.S. Environmental Protection Agency (1977). Compilation of Air Pollutant Emission Factors, 3rd Edition, Research Triangle, North Carolina.

APPENDIX I

INPUT-OUTPUT ANALYSIS

Wainiayaku Plantation

Wainiayaku Plantation yields are 400 te dry copra/year from 800 ha under coconut. Yield is thus 0.5 te/ha-yr.

This compares with total Fiji production for 1980:

22,500 te/81,000 ha = 0.28 te dry copra/ha-yr.

Per Siwatibau:

Fiji coconut plantation production =
1000 kg husk/ha/yr and
400 kg shell/ha/yr

Per Newcombe/CRES/ANU:

2.6 kg husk/kg dry copra x 400,000 kg dry copra/yr = 1,040,000 kg husk/yr

0.9 kg shell/kg dry copra x 400,000 kg dry copra/yr = 360,000 kg shell/yr

Converted to a per hectare basis:

1,040,000 kg husk/yr ÷ 800 ha = 1300 kg husk/ha/yr

360,000 kg shell/yr ÷ 800 ha = 450 kg shell/ha/yr

For purposes of this analysis, we choose the latter estimate.

Moisture content as received is assumed at:

Husk = 50% m.c.w.b.

Shell = 40% m.c.w.b.

It is inefficient to burn biomass with excessive moisture content due to excessive loss of heating value. Therefore assuming air-drying to:

Husk = 40% m.c.w.b.

Shell = 35% m.c.w.b.

then the corresponding air-dried plantation yields are:

1083 kg husk/ha/yr (40% m.c.w.b.)

369 kg shell/ha/yr (35% m.c.w.b.).

For typical operating conditions the boiler/engine/generator consumes 2.0 te air-dried husk + shell per day. Net electrical output is 353 kWh (see Appendix II). Therefore, air-dried biomass input per unit of net electrical output is:

$$\frac{1.3 \text{ te}}{353 \text{ kWh}} = 5.7 \text{ kg/kWh}$$

This compares with typical gasifier-diesel generator set efficiency of 1.5-2.0 kg/kWh. (NB: Gasifiers are typically fed with woody material at 10-25 percent m.c.w.b. and thus the input biomass has greater heating value than the husk + shell fed to the steam boiler.)

The approximate higher heating values (calorific value when oven dry) of the input biomass are:

Husk (estimate) = 4800 kcal/kg = 20.1 MJ/kg

Shell (Siwatibau) = 4560 kcal/kg = 19.1 MJ/kg

Corresponding lower heating values (net of latent heat, heat of vaporization, and hydroscopic bond energy to wood cells) are:

1 kg husk @ 40% m.c.w.b.

0.6 kg oven-dry husk @ 20.1 MJ/kg	= 12.1
-0.4 kg water x 2.8 MJ/kg	= -1.1
	11.0 MJ/kg

1 kg shell @ 35% m.c.w.b.

0.65 kg oven-dry shell @ 19.1 MJ/kg	= 12.4
-0.35 kg water x 2.8 MJ/kg	= -1.0
	11.4 MJ/kg

Combined weighted average energy = 11.4 MJ/kg

Fuel consumption for a 24-hour period is 2.0 te of air dried biomass which is an equivalent energy input of:

2000 kg x 11.1 MJ/kg = 22,200 MJ

= 6,167 kWh

Overall system electrical efficiency is therefore

$$\frac{353 \text{ kWh}}{6167 \text{ kWh}} \approx 5.7\%$$

On a per year basis the fuel required is:

360 days/yr x 2000 kg/day = 720,000 kg

At 1452 kg air-dried husk + shell produced per hectare-year, this implies that
the steam generator set consumes the husk and shell waste produced on about 500 hectares.

APPENDIX II

ELECTRICAL LOAD ANALYSIS

Wainiyaku Plantation

Maximum rated generator output is 30 kVA.

Observed electrical output, daytime operation (70% plant capacity):

415V 3 - phase AC

Phase 1 = 37A x 415V	3 =	8.9 KVA
Phase 2 = 25A x 415V	3 =	6.0 KVA
Phase 3 = 25A x 415V	3 =	6.0 KVA
		20.9 KVA

At 80% rated power factor = 16.7 kW
Less 15% for ancillaries = -2.5 kW
(forced draft fan, induced draft fan, feedwater pump, transfer pump, chemical feed pump, controls)

Net at bus bar = 14.2 KW

Power is distributed as follows:

10% I^2R and distribution losses	=	1.4 kW
1 x 7 HP Copra dryer blower	=	5.5
1 x 5 HP Freezer (60% d.c.)	=	2.4
2 x 2 HP Freezers (60% d.c.)	=	1.9
3 x 1/4 HP Freezers (60% d.c.)	=	0.4
Manager's house	=	0.5
Garage	=	0.6
Laborers quarters	=	1.5
		14.2 kW

Estimated incremental nighttime (7-11 p.m.) load of + 3.0 kW for additional lighting.

Load factor is: $\frac{\text{Average load}}{\text{Peak load}}$

$$= \frac{(360 \text{ days/year})\,[(20 \text{ hrs/day})(14.2 \text{ kW}) + (4 \text{ hrs/day})(17.2\text{kW})]}{(365 \text{ days/year})\,(24 \text{ hrs/day})\,(17.2 \text{ kW})}$$

= 84%

Capacity factor is:

$$\frac{\text{Average load}}{\text{Maximum rated output}}$$

$$= \frac{(360 \text{ days/year})\ (353 \text{ kWh/day})}{(365 \text{ days/year})(24 \text{ hrs/day})(20.4)}$$

$$= 71\%$$

APPENDIX III

COPRA DRYING LOAD ANALYSIS

Wainiyaku Plantation

(Ref: Newcombe/CRES/ANU)

Coconut meat is taken at 50% m.c.w.b. and is reduced to 6% m.c.w.b.

Meat @ 28°C t = 72°C

Water in meat to be removed is 0.79 kg/kg dry copra.

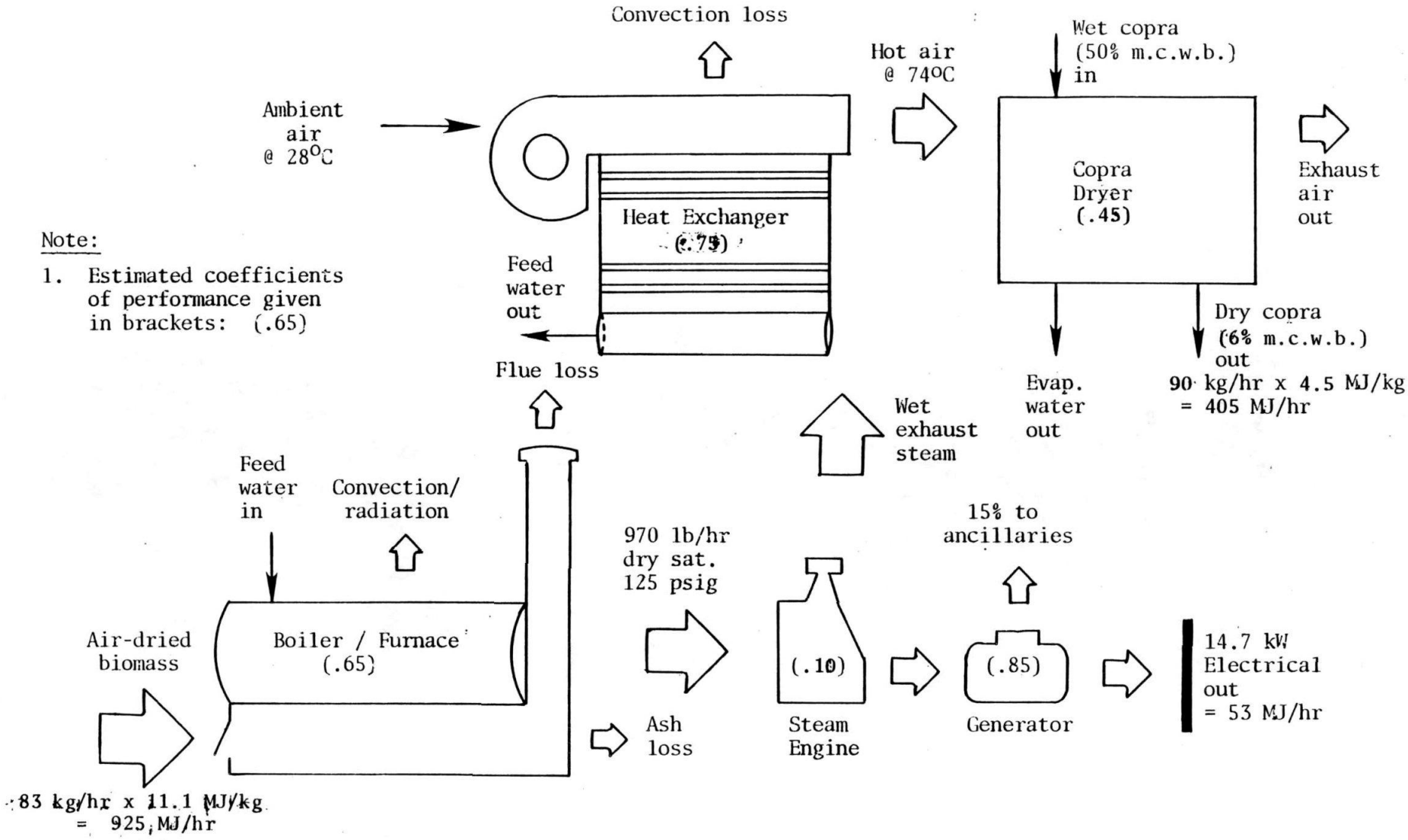
Enthalpy required is:

0.79 kg water x 0.0042 MJ x 72° = 0.24 MJ
plus 0.79 kg water x 2.258 MJ/kg H_2O = 1.78 MJ
2.0 MJ/kg dry copra

From Madang, PNG case study, Chula type oil-fired dryers consume 140 l diesel oil per te dry copra. This is

1401/(4.55 l/gal) x 172 MJ/gal = 5292 MJ or 5.3 MJ/kg

Assuming a diesel fired dryer combustion and heat transfer efficiency of 85 percent this is 4.5 MJ process heat/kg dry copra. This is a dryer efficiency of: 2.0/4.5 = 45%.



Note:

1. Estimated coefficients of performance given in brackets: (.65)

APPENDIX IV

SYSTEM ENERGY FLOW ANALYSIS

Wainiyaku Plantation

APPENDIX V

FUELWOOD DRYING/STORAGE ANALYSIS

Wainiyaku Plantation

As per Figure 2, the heating value of wood cellulose decreases rapidly with increasing moisture content. For direct combustion in boiler furnaces, it is inefficient to burn wood in excess of 40% moisture (wet basis). Depending on ambient weather conditions, coconut husks typically arrive from the plantation copra making area at 40-50 percent m.c.w.b. Drying is therefore required.

Data from the Bora Bora wood gasifier in French Polynesia indicate a density for air-dried stacked coconut husks of 100 kg/m^3. Adding an additional 30 kg for attached shell gives a density of 130 kg/m^3.

The fuelwood stockpile requirement will be determined by the rate of consumption and the rate of fuelwood drying. Copra harvesters using finger cutting commonly cover harvested coconuts with palm leaves for 2-3 weeks to partially dry before husking. Taking 10 days as drying time, stockpile requirement is:

$$2000 \text{ kg/day} \times 10 \text{ days} = 20{,}500 \text{ kg} @ 130 \text{ kg/m}^3 = 150 \text{ m}^3.$$

With a 1.5 m stacking height, this is 100 m^2 storage area.

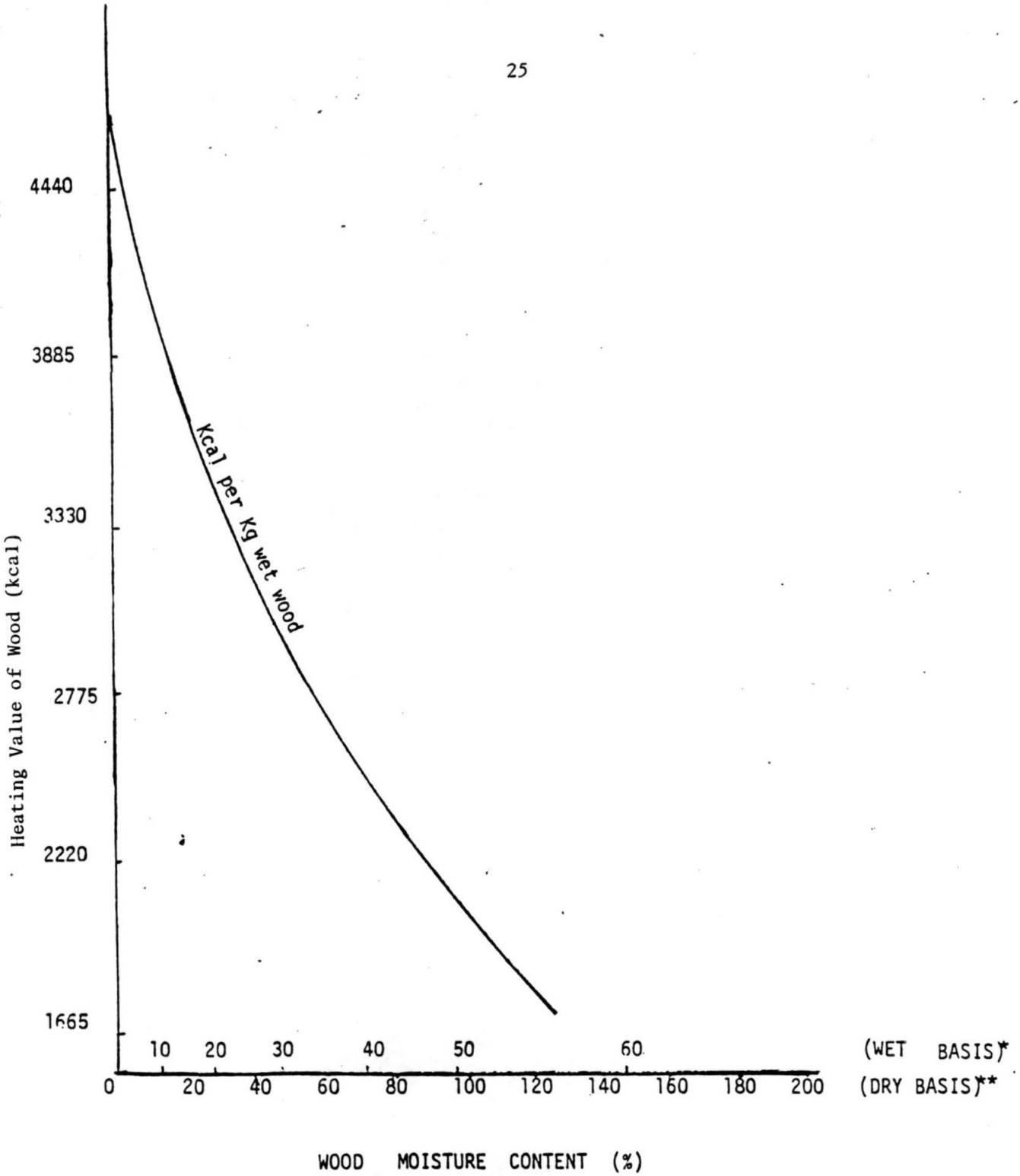


FIGURE 2. EFFECT OF WOOD MOISTURE CONTENT ON ITS HEATING VALUE.

$$* \text{ WET BASIS} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight}}$$

$$** \text{ DRY BASIS} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}}$$

APPENDIX VI

FINANCIAL ANALYSIS

Wainiyaku Plantation

The following cost estimates are for duplicating at late 1983 prices the 30kVA/24kW electricity/copra drying steam system at Wainiyaku:

Capital Cost

o 2 x Copra Driers (pre-existing)	$ - 0 -
o Steam Engine/Generator Set ($900/Kw)	21,600
o Boiler/Furnace, Feedwater System, Hot Air System, and Ancillaries ($2,500/kW)	60,000
o Civil Works ($150/kW)	3,600
o Engineering (10 % of Capex)	8,520
o Installation and Commissioning (15% capex)	12,780
	$106,500

Operations and Maintenance

o Maintenance @ 2% p.a. of capex	$1,704/yr
o Labor	
Stoker/Fireman (1 x 3 shifts)	5,475/yr
Operator/Attendant (20% time)	1,000/yr
Mechanic (10% time)	450/yr
Boiler Inspector (Transportation)	175/yr

Fuel Costs

2.0 te/day x 365 days/yr @ $2.50/te loading & haulage (zero opportunity cost for husk and shell)	$1,825/yr

<u>Net Present Value Analysis</u>

Assumptions:

- o System lifespan is 25 years
- o Discrete discounting with yearly periods

- Annual electricity production is:
  353 kWh/day x 360 days/yr = 127,080 kWh

There are a number of methods by which the benefit of rural electricity production can be estimated:

- Value of fuel displaced (assuming 25 percent efficient diesel generator and diesel @ $0.42/l) = 15.58 ¢/kWh

- Value of electricity at FEA Viti Levu tariff rates = $15.75 ¢/kWh.

- Estimate of full marginal cost of electricity production for rural diesel generating sets with high load factors = 35.00 ¢/kWh.

Similarly, the copra drying benefit can be estimated by:

- Value added of Grade 1 copra vs. undried copra.

- Additional revenue from 100 percent Grade 1 copra vs. mixed Grade 1/Grade 2 copra, with adjustments for differing copra-drying labor costs.

- Value of displaced diesel fuel formerly used to fire copra dryers ≈ $35,000/yr.

- Price charged by Wainiyaku estate of $17.50/te for contract drying of copra (400 te outside + 400 te own)($17.50/te) = $14,000/yr.

For the purposes of this NPV analysis we have conservatively chosen the last figure for the value of copra drying. Net present values were then calculated for varying assumptions of electricity benefit.

We are aware that the copra dryer blower fan consumes a substantial portion of the electric power generated. However, oil-fired copra drying also employed forced draft warm air circulation and consumed an equal amount of electricity.

COMPRAN DATA INPUT

Plantation Scale Cogeneration System

Financial Analysis

- 25 year planning horizon
- Discount rate = 0.05/0.10

#	Description	Base Price	Price Scalars	Quantities	Quantity Scalars
1.	Maintenance	1,704.00	1.0	1.0	1.0
2.	Stoker/Fireman	5,475.00	1.0	1.0	1.0
3.	Operator/Attendant	1,000.00	1.0	1.0	1.0
4.	Mechanic	450.00	1.0	1.0	1.0
5.	Boiler Inspector	175.00	1.0	1.0	1.0
6.	Wood Fuel	2.50	1.0	730.0	1.0
1.	Electricity	0.01	15.75/35.00	127,080	1.0
2.	Inside Dried Copra	17.50	1.0	400	1.0
3.	Outside Dried Copra	17.50	1.0	400	1.0

Capital Cost: $106,500.00 in year 1. 10% financing, no grace period with equal annual payments over 8 years.

- Breakeven analysis on output #1 electricity price.

APPENDIX VII

FINANCIAL ANALYSIS

10kW Village-Level System

Closed Loop System

The following are indicative cost estimates for a 12.5 kVA/10kW electricity/copra drying system installed in a rural village environment. Assume the system operates 325 days/year, 16 hours/day 40 percent load factor .

Capital Costs

o Steam Engine/Generator Set ($950/kW)	$9,500
o Boiler/Furnace, Feedwater System, Hot Air System, and Ancillaries ($4,000/kW)	40,000
o Civil Works ($200/kW)	2,000
o Engineering (10% of capex)	5,150
o Installation and Commissioning (15% capex)	7,725
	$64,375

Operations and Maintenance

o Maintenance @ 2% p.a. of capex	$1,030/yr
o Labor	
Stoker/Fireman (1 x 2 shifts)	$3,250/yr
Operator/Attendant (20% time)	$ 500/yr
Mechanic (3 visits/yr inc. transportation)	$ 525/yr
Boiler Inspector (Transportation)	$ 175/yr

Gross annual electrical production is:

(10kW)(16 hrs/day)(325 days/yr)(40% L.F.)	=	20,600 kWh
Less 15% for ancillaries		-3,120
Net annual production:		17,680 kWh

Fuel costs are estimated at
(0.6te/day)(325 days/yr)($2.50/1000 kg) = $ 487/yr

Fuel can be obtained from:

$$\frac{195{,}000 \text{ kg/yr}}{1452 \text{ kg/ha-yr}} = 135 \text{ ha of coconut plantation}$$

Net Present Value Analysis

Assumptions

- o Estimated copra throughput is:
  (500 ha under coconut) (0.28 te/ha) = 140 te/yr.

- o Copra dryer blower motor of 1.5 HP (1.1 kW) is powered by system excess generating capacity relative to household demand.

- o Electricity to consumers valued at:
  (17,680 kWh/yr)($0.50/kWh) = $8,840/yr.

- o Copra drying valued at:
  (140 te/yr)($17.50/te) = $ 2,450/yr.

COMPRAN DATA INPUT

Village Scale Closed Loop System

Financial Analysis

- o 25 year planning horizon
- o Discount rate = 0.05/0.10

	#	Description	Base Price	Price Scalar	Quantities	Quantity Scalar
Inputs	1.	Maintenance	1,030.00	1.0	1.0	1.0
	2.	Stoker/Fireman	3,250.00	1.0	1.0	1.0
	3.	Operator/Attendant	500.00	1.0	1.0	1.0
	4.	Mechanic	525.00	1.0	1.0	1.0
	5.	Boiler Inspector	100.00	1.0	1.0	1.0
	6.	Wood Fuel	2.50	1.0	195.0	1.0
Outputs	1.	Electricity	0.50	1.0	17,680	1.0
	2.	Dried Copra	17.50	1.0	140	1.0

Capital Cost: $64,375 in year 1. 7.5% financing, no grace period with equal annual payments over 8 years.

- o Breakeven analysis on output #1 electricity price.

APPENDIX VIII
ECONOMIC ANALYSIS
10 kW Village-level System

Open Loop System

Assumptions:

- o Site is a Viti Levu rural village with access to continuous feedwater source.
- o Fuelwood source is wood wastes at $10/te
- o For simplification fuel rate is taken as 5.7 kg/kWh

A. 6 hr/day Case

Capital Costs

o Steam Engine/Generator Set ($950/kW)	$9,500
o Boiler/Furnace, Feedwater System, and Ancillaries ($2,500/kW)	25,000
o Civil Works ($200/kW)	2,000
o Engineering (10% of capex)	3,650
o Installation and Commissioning (15% capex)	5,475
	$45,625

Operations and Maintenance

o Maintenance @ 2% p.a. of capex	$ 750/yr
o Labor	
Stoker/Fireman	1,440/yr
Operator/Attendant (20 % time)	500/yr
Mechanic (3 visits incl. transportation)	300/yr
Boiler Inspector (transportation)	100/yr

Fuel Costs

Gross annual electricity production is:

(10kW)(360 days/yr)(6 hrs/day)(80% L.F.)	=	17,280 kWh
Less 15% for ancillaries		-2,592
Net annual production:		14,688 kWh

Fuel costs are:

(14,688 kWh/yr)(5.7 kg/kWh)($10/1000kg) = $ 837/yr

B. 12 hr/day

- o Capital costs are identical to 6 hr/day Case
- o Stoker/Fireman cost is $2,880/yr
- o Gross annual electricity production is:

(10 kW)(360 days/yr)(12 hrs/day)(80% L.F.)	=	34,560 kWh
Less 15% for ancillaries		-5,184
Net annual production:		29,376 kWh

o Fuel Costs are:

(29,376 kWh/yr)(5.7 kg/kWh)($10/1000 kg) = $1,674/yr

C. 24 hr/day Case

- o Capital costs are identical to 6 hr/day Case
- o Stoker/Fireman cost is $5,760/yr
- o Gross annual electricity production is:

(10kW)(360 days/yr)(24 hrs/day)(80% L.F.)	=	69,120 kWh
Less 15% for ancillaries		-10,368
Net annual production:		58,752 kWh

- o Fuel costs are:

(58,752 kWh/yr)(5.7 kg/kWh)($10/1000kg) = $3,348/yr

COMPRAN DATA INPUT

Village Scale Open Loop System
Economic Analysis

- 25 year planning horizon
- Discount rate = 0.10

	#	Description	Base Price	Price Scalars	Quantities	Quantity Scalars	Inflation Rates	Options
Inputs	1.	Maintenance	750.00	1.0	1.0	1.0	0.00	Traded @ 1.20
	2.	Stoker/Fireman	1440.00	1.0	1.0	1.0/2.0/4.0	0.00	Underemployed @ 0.50
	3.	Operator/Attendant	500.00	1.0	1.0	1.0	0.00	Unemployed
	4.	Mechanic	300.00	1.0	1.0	1.0	0.00	---- ----
	5.	Boiler Inspector	100.00	1.0	1.0	1.0	0.00	---- ----
	6.	Wood Fuel	10.00	1.0	83.7	1.0/2.0/4.0	0.00	---- ----
Output	1.	Electricity	0.50	1.0	14,688	1.0/2.0/4.0	0.00/0.02	---- ----

Capital Cost: $46,875 of which $35,000 foreign exchange @ 1.20 shadow exchange factor

- Breakeven analysis on output #1 electricity price
- IRR option

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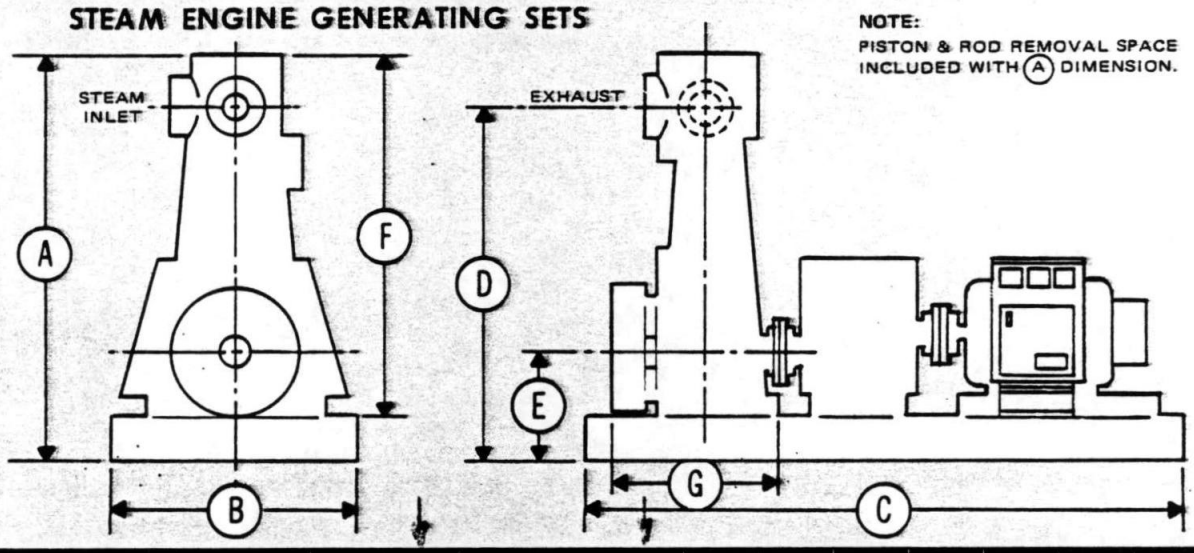
ENGINE SIZES AND DIMENSIONAL DATA

STEAM ENGINE GENERATING SETS

NOTE:
PISTON & ROD REMOVAL SPACE INCLUDED WITH (A) DIMENSION.



ENGINE-GEN-SET		4" SINGLE	5" SINGLE	6" SINGLE	7" SINGLE	8" SINGLE	9" SINGLE	10" SINGLE	8" DUPLEX	9" DUPLEX	10" DUPLEX	12" DUPLEX	14" DUPLEX
BRAKE HORSEPOWER	BHP	8.9	17.5	25.5	33.3	48.5	63.8	92.0	121.0	150.0	182.0	219.0	290.0
KILOWATT	KW	5	10	15	20	30	40	60	80	100	125	150	200
KILOVOLT-AMPERE	KVA	6.3	12.5	18.7	25.0	37.5	50.0	75.0	100.0	125.0	156.3	187.5	250.0
ENGINE	RPM	600	555	475	475	355	355	355	400	355	355	325	275
RATIO SPEED CHANGER		3.00:1	2.16:1	2.53:1	2.53:1	5.06:1	5.06:1	5.06:1	4.50:1	5.06:1	5.06:1	3.69:1	4.36:1
SERVICE FACTOR		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
GENERATOR SPEED		1800	1200	1200	1200	1800	1800	1800	1800	1800	1800	1200	1200
APPROX. WATER RATE PER KILOWATT HR.		65.7	64.2	60.2	59.7	55.7	60.5	54.0	54.8	52.8	51.3	49.6	47.1
APPROXIMATE DIMENSIONS IN INCHES AND *MILLIMETERS*	A	64	76	87	97	103	109	128	105	111	125	144	168
		1626	*1930*	*2210*	*2464*	*2616*	*2769*	*3251*	*2667*	*2819*	*3175*	*3658*	*4267*
	B	20	25	31	36	45	45	50	45	45	50	50	65
		508	*635*	*787*	*914*	*1143*	*1143*	*1270*	*1143*	*1143*	*1270*	*1270*	*1651*
	C	82	88	91	110	116	135	158	146	169	197	212	233
		2083	*2235*	*2311*	*2794*	*2946*	*3429*	*4013*	*3708*	*4293*	*5004*	*5385*	*5918*
	D	47	58	62	70	77	81	96	79	83	94	108	129
		1194	*1473*	*1575*	*1778*	*1956*	*2057*	*2438*	*2007*	*2108*	*2388*	*2743*	*3277*
	E	17	19	22	25	28	29	35	29	31	35	39	49
		432	*483*	*559*	*635*	*711*	*737*	*889*	*737*	*787*	*889*	*991*	*1245*
	F	46	60	65	77	84	88	99	84	88	99	113	135
		1168	*1524*	*1651*	*1950*	*2134*	*2235*	*2515*	*2134*	*3235*	*2515*	*2870*	*3429*
	G	29	35	38	42	46	51	56	82	92	103	116	135
		737	*889*	*965*	*1067*	*1168*	*1295*	*1422*	*2083*	*2337*	*2616*	*2946*	*3429*

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GUIDELINES FOR STEAM ENGINE PROPOSAL

By Sam Pintz
Pacific Energy Program

A. A study proposal is sought on the technical and economic aspects of installing steam engines in remote, rural communities in selected South Pacific nations. The study shall include a rural community in each of the following South Pacific countries...The study is to be undertaken to a prefeasibility level of detail and will include end use applications for the generation of electricity and for the provision of low grade process steam for copra drying.

B. Technical aspects to be included in the proposal shall include, but not be limited to the following:

1. The availability of a biomass fuel resource on both a seasonal and annual basis, including reserve storage and stockpile requirements.

2. Operational problems inherent in organizing and using biomass fuels eiyther as a supplemental or primary energy source.

3. Considerations relating to the water chemistry and steam conditions necessary to supply the electricity and crop drying application.

4. An estimate of the avialability of operating and maintenance requirements including -

   - the appropriate skill levels of operating personnel
   - the appropriate skill levels of maintenance personnel
   - the availability or training requirements for obtaining these skill levels
   - indicative estimates of the spare parts inventory which might be necessary to service the steam engines and associated equipment

5. The character of end use demand for the steam engine application, including -

   - o the magnitiude and character of the applications
   - o daily, monthly and season demand fluctuation
   - o the complimentary or competitive nature of the two end use applications

6. Anticipated compatibility of off-the-shelf steam engines with standard auxiliary equipment necessary to achieve the end use applications

7. The ability of standard equipment to withstand the conditions common in humid, tropical environments. This assessment should provide information on the effects of corrosion, any performance derating associated with sea level operation and the deterioration of non-metallic components (e.g. seals, hoses etc.). A life expectancy shall be assumed and defended.

C. The economic evaluation shall include, but not necessarily be limited to the following:

   (1) Indicative estimates for all capital costs itself. These costs shall be distributed by the following component classes -

   - o Fuel system, steam system, steam engine, (with auxiliary) electrical system, crop drying system, spare parts inventory and storage
   - o Non-equipment construction costs including site preparation, costs of structure and internal auxiliaries

(2) An estimate of operational costs, broken down into the following constituents -

- o Personnel costs for operations, maintenance and overhead/administrative function (including training)
- o Costs associated with fuel collection and storage
- o Other operating materials costs

(3) Based on the above cost estimates, the consultant shall develop a time discounted cost of electricity (e.g. US cent/KWH) in which all system costs (minus those directly associated with distribution of crop drying heat) shall be attributed to electricity production. Appropriate load and capacity factor assumptions shall be set out together with thermal efficiency assumed for each system component as well as the system as a whole.

***

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