TECHNICAL BULLETIN

No.2

Cost Comparisons for Different Energy Systems of Producing Electricity on Outer Islands (atolls)

Office of Planning & Statistics
Majuro, Marshall Islands
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FOREWORD

Currently, the Republic of the Marshall Islands is emphasizing socio/economic development of the outer islands as a major part of its overall development plans. The results of the analysis strongly suggest that coconut oil can be very useful in stimulating outer island activity. The author of this second bulletin, Mr. Stephen Kasper, has used analytical techniques which should form part of all economic evaluations in the Marshall Islands. To close, I would to thank Tom Cole, (Resources and Development) Suzanne Cowan, (Federal Programs Coodinator) and officials at Tobolar for their expert assistance in the production of this bulletin.

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The Marshall Islands' Five Year Development Plan, 1983-87, emphasizes outer island development, and coincides with the South Pacific Commission's integrated atoll development program currently being instituted. The term integrated is used to mean development of many interlocking aspects of an economy simultaneously. It also implies the use of existing local resources. One such resource is coconut oil. In the past it was used as food and fuel but this is no longer true. Given the current low price of coconut oil, it has been suggested that it might again be profitably used as a fuel substituting for diesel oil in the production of electricity. What follows is an analysis of this alternative use.

A number of experiments have been conducted in the Phillipines and other Pacific countries using coconut oil as a fuel. The greatest amount of research has been done at the Phillipine National Oil Company's Energy Research and Development Center. In tests of compression ignition engines over long periods of time, the thermal efficiency of coconut oil was found to be 33.3 percent as compared to diesel fuels 32.4 percent.[1] The average indicated horse power provided in the tests was approximately 6.83 for both fuels. In mileage tests performed with buses operated by the Manila Transit System it was found that a 5 percent greater volume of coconut oil was used to travel the same distance under the same conditions than diesel fuel. This can be interpreted to mean that diesel engines operate almost equally well with coconut oil as they do with diesel oil.

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[1]Ibarra E. Cruz, PNOC Lab Report, Manila, 1982

There are other factors involved besides fuel efficiency. Two in particular are of importance here: 1) formation of solid particles in the fuel; and 2) fuel filtering. Formation of solid particles occurs in coconut oil at temperatures of 68-77 degrees F; the purer the grade of oil, the higher the solidification temperature. This is unlikely to be a problem in the Marshalls since temperatures very rarely fall below 75°F, and average above 80°F. There may be times, however, when it will be necessary to preheat the oil before running the generator especially in cases of cold starting. Some additional expense may have to be incurred to provide this capability.

Fuel filtering problems are potentially far more costly. Combustion of coconut oil in diesel engines is equally efficient when compared to diesel fuel in well tuned engines, but after long periods of operation coconut oil tends to form deposits on the engine injectors.[2] The deposits cause poor combustion, and may eventually contaminate the engines' lubricating oil which would in turn cause more severe damage. To correct for this, engines running on coconut oil must be well maintained. The oil should be run through disposable filter elements before being used in diesel engines.

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[2]Richard K. Solly, Utilization of Coconut Oil as a Fuel for Petroleum Diesel and Kerosene Substitition, South Pacific Commission, Papeete, 1982.

A) Capital Costs

The estimated costs of a power generating system dependent on a diesel generator are as shown below.

FIGURE 1 - Estimated Costs of Using Coconut Oil as a Substitute for Diesel Fuel

Installation	Cost
10 KW Generator	$4,700.00
Expeller	2,750.00
Storage Shed (materials)	1,500.00
sub-total	8,950.00
Operation	
Coconut Meat (557.2 lbs. at $0.034)	18.83 per day
Labor to Operate Expeller	1.25 per hour
Maintenance (6% of total installation cost)	537.00

The costs referred to in Figure 1 are based on the following sources. The generator price is a quote for a Yanmar 10KW diesel generator. The expeller discussed is referred to in the Pacific Energy Programme's report on coconuts.[3] It is a Cooker 'SS' type, requires 5.9KW of energy for its own operation, and can process 71 kilograms (156.53 lbs) of coconut meat into 25 litres (6.6 gallons) of coconut oil every hour. The oil would in turn be used as fuel for future generator operation. The storage shed cost is based on the prices for materials necessary to construct a 10 ft. square structure with a

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[3]Pacific Energy Programme, Report on Coconuts, Noumea, New Caledonia, 1982.

concrete floor, plywood walls, and a tin roof (the cost of drums for oil storage is included in this figure also).

B) Operation Costs

It is expected that the price paid for copra in the outer islands will rise in the near future since coconut oil prices, along with most other commodities, seem to have bottomed out. The figure chosen, $0.034, is based on this expectation, and is subject to change.[4] It is anticipated that the generator will run for sixteen hours a day since continuous operation is not necessary to provide desireable freezer and refrigerator temperatures if such appliances are properly maintained. It is also anticipated that lights will not be required for lengthy periods at night.

Based on the above assumptions, and a fuel consumption rate of 1.05 gallons per hour, the generator will require approximately 16.8 gallons of coconut oil fuel per day or 6,132 gallons per year.[5] To produce this quantity of oil will require that 23.5 gallons of oil be processed daily in the expeller.[6] At maximum capacity, the expeller can process 156.53 lbs. of coconut meat per hour. Since 3.56 hours of expeller operation are needed daily, 557.25 lbs. of coconut meat will be needed daily, at a cost of $18.83 per day.

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[4]This paper will refer to two types of coconut meat, wet and dry. Dry is copra as referred to normally; wet is coconut meat just out of the shell before drying. Since the oil content by weight of one pound of copra is equal to 1.775 lbs. of meat, the prices have been adjusted to reflect this: copra=$.06, and meat=$.0338.

[5]Ibarra Cruz, ibid.

The cost of labor is set at $1.25 to reflect what is considered to be a reasonable value for this type of labor. At approximately 4 hours per day of expeller operation, and 3 hours for oil handling (storing in drums) and routine maintenance such as cleaning of filters, total cost could be figured at $1.25 times 7 hours a day total, or $8.75 per day.

Maintenance in a system such as this typically runs about 3 percent of the total machinery cost per year on the average. This has been determined by observation of various other coco-fuel experiments in the Pacific. On an outer island in the Marshalls, this maintenance figure can be expected to be higher, possibly as much as 6 percent. The reasoning is that supply lines are not reliable and, consequently, spare parts are not always going to be available when they are needed. Maintenance costs will, however, depend mainly on whether or not a good mechanic is locally available.

C) Electricity Use

The load that is expected to be generated by appliances is as shown below.

one 16 cubic ft. freezer	=	500 watts
one 14 cubic ft. regrigerator	=	500 watts
ten 100 watt bulbs	=	1000 watts
one oil expeller	=	5900 watts
Total		7900 watts

An eight kilowatt generator would be large enough to run this system

[6]This figure can be obtained by dividing gallons per year by work-days, or 6,132/261=23.49. Then, since the rate of oil production is known to be 6.6 gallons per hour, the number of hours of operation per work-day can be determined as 23.49/6.6=3.56. Lastly, since 156.53 lbs. of coconut meat are needed per hour to produce at the above rate, approximately 3.56 x 156.53=557.25 lbs. will be needed every working day as raw material for the expeller, or $18.83 per working-day at a price of $0.0338 (0.034) per pound.

assuming that system components are installed properly, and that they are well maintained. However, based on independent estimates from experts at Tobolar and the Department of Resources and Development, it has been decided to include a 10KW generator to power the system. This size could easily handle the average load even during start-up, would allow for adverse load factors, and could support some additional future load.

D) Annualized System Costs

The annual costs of this system based on an expected 10 year lifetime are as shown below.

		Annual Costs
Expeller		$ 426.55
Generator		729.02
Storage Shed		232.67
	annualized sub-total	$1,388.24
Labor (7 hrs. per day/261 days)		2,283.75
Raw Material		4,915.49
Maintenance		537.00
	non-annualized sub-total	$7,736.24
	Total	$9,124.48

Annualized costs are not a simple division of capital outlay by 10. They are the capital costs multiplied by a capital recovery factor which estimates the necessary return on capital expenditure over the length of a 10 year time period.[7] This more adequately reflects the true annual cost since it takes into account the fact that eventually the equipment will depreciate to zero value, and will then

[7] George A. Taylor, Managerial and Engineering Economy, New York, 1980, p. 513. Details for the procedure of calculating capital recovery costs can be obtained at the Planning Office.

have to be replaced.

E) Equipment Alternatives

One variable in the above system that could be called into question is the type of expeller, since it does require large amounts of power, and more technical experience to operate and maintain than another type of expeller system that could be substituted for it. In particular, the Cooker 'SS' type could be replaced by a Hander expeller system which does not heat the raw material, but chops and presses it. Experts at Tobolar who are familiar with both types of expeller advise that the Hander equipment is a better choice for outer island energy production despite the fact that the initial capital required is $11,020.00 as opposed to $2,750.00.

Costs break down as follows if the Hander expeller system is substituted for the Cooker 'SS' type system.

Expeller	$3,600.00
Power Chopper	$4,090.00
Filter Press, Type 'A'	$3,330.00
Total	$11,020.00

This system uses less power, only 4.8KW as compared to 5.9KW which means a slightly smaller generator could be used to power the system. Assuming all other loads remain the same, an 8KW generator would be sufficient. This results in a lower capital outlay for the generator; in the amount of $3,760.00 or a decrease of $940.00. Since the rate of production of oil is approximately equal to the cooker system, labor costs are also approximately equal. The Hander chopper/expeller system uses dried copra as raw material rather than wet coconut meat, at a rate of 88.185 lbs. per hour compared to 156.53 lbs. per hour, but the percentage of oil by weight is approximately equal. onsequently, the cost breakdown for this system over a 10 year period is as shown below.

		Annual Costs
Hander Expeller		$ 558.40
Power Chopper		634.40
Press Filter Type 'A'		516.52
8KW Yanmar Generator		583.21
Storage Shed		232.67
	annualized sub-total	2,525.20
Labor (7 hrs/day - 261 days)		2,283.75
Maintenance (at 5% of installed Capital cost)		976.80
Raw Material		4,915.91
	non-annualized sub-total	8,176.46
	Total	$10,701.66

The total cost of raw material in this case was figured as before. The fuel required by the generator is 16.8 gallons per day. At 365 days generator operation, this is 6,132 gallons a year. At 6.6 gallons per hour of oil production, this would require 313.915 lbs. of processed copra per day. At $0.06 per pound of copra, the annual cost of raw material is $4,915.91, and as it should be, is equal to the raw material cost of the Cooker 'SS' type system.

In sum, there are cost differences between the two systems despite the fact that they produce oil at the same rate. After annualization, the expeller/chopper system costs $1,577.18 more per year than the Cooker 'SS' type system, or an increase of 17.3 percent.

This cost factor could very well be different if the 'SS' type needs more maintenance than accounted for in the previous example. In either case, the local production of oil to be used as fuel for the generation of electricity appears to be viable. For a population of 500, the break even cost per capita per month would be as follows.

Cooker 'SS' Type	Chopper/Expeller
Total Cost Per Year	
= $9,124.48	=$10,701.66
Divided by Months = 12	
= 760.373	= 891.805
Divided by 500 People	
= $1.52	= $1.78

While this is not a large payment for the services that would be provided, it is possible that it can not be paid in full by families that are wholly dependent on copra for their income. At a price of $0.06 per pound, a family of 10 would need to produce 297 pounds of copra per month to pay their $17.80 share of the atoll's electricity bill. This may or may not be acceptable to families in such a position. It would be possible to determine the answer by including the question as part of an outer island survey.

F) Solar Option

As an alternative to using an outer atoll's copra as fuel instead of a cash crop for export, solar energy could be used. A solar system for generation of electricity will have a much higher installation cost but maintenance and operation costs would be much lower.

The life of the system would be longer; whereas the coconut oil expeller system has an estimated life of 10 years, a solar system conceivably would not wholly depreciate for twice that time. This will be taken into account in the cost breakdown when the capital recovery factor is applied.

There are a number of factors involved in the production of solar energy that make it difficult to compare to the systems previously discussed. The most important is that a solar photo-voltaic system stores the energy that it produces in batteries - in effect, it is two systems; one to produce, and the other to store and distribute. A generator, though, must be operating to be used; it has no storage capability. Consequently, the fact that appliance duty cycles are not continuous can not be taken advantage of. To keep a freezer cold 24 hours a day, a generator must run for about 16 hours depending on how often the freezer is opened. After the generator is off, the freezer should not be opened. With a solar system, however, the freezer's duty cycle can be taken into account. That is, a freezer does not continuously draw power. If it was never opened, it would only draw on a continuous power supply for approximately 5 hours per day. The following cost breakdown will assume frequent openings of appliances, and provide for enough power to supply a freezer and a refrigerator for 12 hours of power usage per day.

The following assumptions will be made to estimate the costs of a solar energy electrical generation system.

1) The solar panels used will have the capability to produce 35 watts at peak, or 35Wp.[8]

2) A 35Wp solar panel can produce a total of 155 watt hours per day in the Marshall Islands on the average.[9]

3) Power demanded is equivalent to 2,000 watts per day, at 12 hours per day. 24,000 watt-hours per day divided by 155 watt-hours of demand equals 155 panels needed.

Appliances will use energy whether or not the panels are generating power. This includes nights, and days when the maximum peak wattage is not provided due to overcast skies. Consequently, this possibility has to be provided for. The industry standard is to use enough batteries so that power can be stored for 5 consecutive days of use without recharging. Since batteries are very expensive, two cost breakdowns will be shown below; one in terms of the above assumption, and one that will allow for only half the above indicated power storage capacity.

The number of batteries necessary to store power for a system is determined by calculating the amp hours needed per day. In this case, the load is 2,000 watts times 12 hours per day operation time (i.e. power usage). This cost breakdown will assume that the C and D Battery Company's Type QP (12v-96amp hr.-deep cycle) batteries will be used. Volts multiplied by amps equal watts, so 24,000 watt hours divided by 12v gives us the required amp hours, 2,000. Since the C and D

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[8]The term peak is used to represent amount of sunlight, or insolation received by solar modules in a particular area. In the Marshalls, peak insolation is received for 4.5-5.0 hours per day; approximately 5KWh per meter squared (panels) per day of energy can be produced.

[9]David A. Schaller, and Renal W. Larson, Photo Voltaic Applications for Remote Island Needs, Denver, 1982.

battery is a 96 amp hour battery, the system will use 21 of them. To provide storage for 5 consecutive days of non-charging, the system will require 105 batteries. (To provide storage for 50 percent less non-charging time, the system will require only 53 batteries).

Another cost factor is the total of electrical equipment that will be needed such as voltage regulators, rectifiers, and inverters. Prices vary, but on the average a charge controller will cost about $230.00 and an inverter will cost about $3,000.00.[10] The rest of the electrical equipment, such as wire, volt meters, wire harness assemblies, and battery cables can be roughly calculated at about one percent of the total installed cost. The last factor to be considered is mounting hardware for the solar panel modules. This can cost up to $120.00 per module, but racks can also be purchased which can hold many panels at once in a large array at a cost of approximately $50.00 per panel. The cost breakdown below will assume that these racks will be purchased.

Given the above, the costs of a solar powered electrical generation system to provide energy for appliances with a total load of 2,000 watts are as shown below.

Solar Panel Molules (Arco 35Wp, 155 at $375.00)	$58,125.00
Batteries (C and D, 12v-deep cycle-96 amp hr.) (21 x 5 at $165.00)	17,235.00
Charge Controller	230.00
Inverter	3,000.00
Electrical Equipment (1% of modules, batteries controller, and inverter)	790.00
Mounting Hardware (155 at $50.00)	7,750.00

10 Schaller and Larson, ibid.

Storage Shed (same as for generator/expeller system)	1,500.00
Maintenance (3% per annum of capital costs minus batteries)	2,141.85

It is assumed that the system life is 20 years. With a battery life of four years for the C and D batteries, they will have to be replaced 5 times. The total cost of batteries then is $86,625.00. If, however, it is assumed that the system needs to provide for only 2½ days consecutive non-charging, then only 53 batteries will be needed at a total cost of $43,725.00. Annualized costs can then be calculated as shown below applying a capital recovery cost factor exactly as in the previously discussed generator/expeller system (see footnote 7).

	Annual Costs
Solar Panel Modules	$ 6,507.10
Batteries (5 day non-charge)	9,697.67
(2½ day non-charge)	4,895.01
Charge Controller	25.75
Inverter	335.85
Electrical Equipment	88.44
Mounting Hardware	867.61
Storage Shed (10 years plus 10 years) $1,500 plus 2362.65)	428.40
5 day non-charge annualized costs sub-total	$17,950.82
2½ day non-charge annualized costs sub-total	$13,148.16
Maintenance	2,141.85
Total yearly cost, 5 day non-charge	$20,092.67
Total yearly cost, 2½ day non-charge	$15,290.01

G) Generator/Expeller System Compared to Solar

The least expensive solar total is now seen to be $4,588.35 greater than the most expensive generator/expeller system. This is a 43 percent difference in terms of total annual costs. On an outer atoll with a population of 500, the cost per capita per month would be $2.55 or $0.77 more per capita per month. For an outer island family of ten, the difference between monthly costs is [(2.55)(10)]-[(1.78)(10)] or $7.70.

The space requirements for solar are much greater, but not prohibitively so. The solar modules are approximately 4 ft. by 3 ft., or 12 square ft. Since 155 are needed, they would most likely be put in an array of 13 by 12 with approximately 6 inches of space between any two modules. Total area covered would be [(13x3) + (12x6)inches] plus [(12x4) + (11x6)], or 45 by 53.5 feet. This is approximately 5 percent of one acre. According to experts at Resources and Development, this area could support 4 healthy coconut trees. In terms of lost space for agricultural production then, it can be seen that an array this large does not have a high opportunity cost.

The solar power system will not provide any secondary economic benefits, though, whereas the generator/expeller system will. The by-product of the generator/expeller system is copra cake. This could be combined with fish meal, or anything else that is locally available to make animal feed. At 33 percent of dried copra weight, this would amount to approximately 104 pounds per day of copra cake. This could be sold to help pay for the system.

The generator/expeller system would also provide jobs. It would need a mechanic for daily maintenance, (part time) and one full time laborer to operate the system, and keep records. Jobs would be directly created for copra makers on a steady basis. In total, this system would employ 6-7 people wherever it is put into operation. Solar power systems would only employ 1-2 people throughout the Marshalls to perform routine maintenance. Lastly, generator/expeller systems which are operated to produce more oil than is needed to run the generator could provide oil for production of oil products such as soap, and thereby contribute to import substitution by increasing local manufacturing output.

Before summarizing, certain points not previously mentioned should be noted. Most importantly, a number of assumptions have been made in this paper that may have to be revised in the future. One example is the price of copra. It will almost surely rise in the future, but it can not be exactly predicted. It is unlikely that it will rise in an amount sufficient to make the generator/expeller system more costly than solar power, but it is possible that diesel fuel may become an attractive alternative for system use. Given this possibility, a much more extensive analysis of secondary economic benefits may have to be undertaken to determine the value of the generator/expeller system's by-products. Also, given the price of copra, the opportunity cost of using it as fuel in place of using it as an export commodity will have to be analyzed as well. Other factors involved in the analysis have also had assumptions made about them that may require further future analysis, and this implies that if this information is not applied before 1985, the costs included herein will probably have to be recalculated to ensure validity.

H) Summary

There are two types of systems that could be operated on outer islands (atolls) to produce electricity. One would employ a generator fueled by coconut oil produced locally with an expeller. The other would be solar powered. The capital costs of a generator/expeller system would be less than that of the solar powered system, and would provide secondary economic benefits for the areas where they are in operation. A solar powered system would have lower fuel and maintenance costs, but would provide no secondary economic benefits. In conclusion, this bulletin will recommend that generator/expeller systems be purchased for the production of electricity on outer atolls. The only exceptions to this conclusion are those atolls which can not support the system's use of 16.8 gallons of coconut oil per day, (i.e. 314 lbs. of copra or 557 lbs. of wet coconut meat per day) or where populations are much less than 500.

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