Center For Economic Research on Africa
School of Business
Montclair State University
Upper Montclair, New Jersey 07043

Financial and Economic Analysis
of
Selected Renewable Energy Technologies
in Botswana

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Phillip LeBel
Professor of Economics
Montclair State University
Upper Montclair, New Jersey 07043
Lebelp@mail.montclair.edu

Abstract

This paper examines the economic efficiency of alternative renewable energy technologies in raising the technical efficiency of energy consumption in Botswana, in reducing its dependence on imported energy resources, and in generating domestic income. It builds on feasibility studies of the US AID-financed Botswana Renewable Energy Technology project, and provides estimates of the financial and economic net present values of a sample of energy conserving technologies.The technologies covered are: artisan-produced domestic stoves, retained heat cookers, and small-batch solar hot-water heaters. Each has been selected for its potential to reduce fuelwood consumption, a primary source of household energy resources. In purely financial terms, the stoves appear to be the most economical, followed by the retained heat stoves. The small batch solar hot water heaters do not hold promise under current relative prices. In all cases, the financial analysis has been complicated by the absence of accurate measures of fuelwood prices, and for which we have considered the use of shadow price alternatives to substantiate these findings. For Botswana, factor technology substitution is thus sensitive to the prevailing price of fuelwood common property resources.

I. Introduction

A. Overview of the Botswana Economy

Surrounded by South Africa to the South, Namibia to the West and North, and Zimbabwe to the East, Botswana is a semi-arid country of remarkable contrasts. Its 1985 estimated population of just over one million live in an area of 582,000 square Kilometers, making Botswana one of the more sparsely populated countries in all of Africa. One reason for this relationship is that four fifths of Botswana's relatively flat landscape consists of Kgalagadi sandy soil that can support at most savannah-type thorn vegetation. Critical to this pattern is the supply of water. Apart from the Okavango River swamp basin in the northwestern part of the country, there are no permanent bodies of water in the country. Moreover, rainfall is erratic, ranging from 700 millimeters in the extreme north to some 200 millimeters in the extreme southwest. Not surprisingly, drought has been a recurring problem. For these reasons, three quarters of the population of Botswana live mostly in rural communities in the southeastern part of the country that accounts for only ten percent of the land area. At the same time, population growth, estimated at over three percent per year, is being accompanied by one of the highest rates of urbanization on the African continent.

As a still largely rural economy, Botswana has traditionally derived the bulk of its income from agriculture, with livestock constituting one of the principal sources of domestic and export revenue. However, in recent years, Botswana has developed its mineral resources, and diamonds now account for the largest single source of export revenues, as well as one of the principal sources of government tax revenue. Though Botswana diamonds, and to a comparable extent, copper and nickel resources, have suffered from the recent decline in world primary commodity prices, the effects of worldwide deflation have been less severe on the economy than in some other developing countries because of the relatively high proportion of the population that still operates within the sphere of traditional subsistence agriculture. Consequently even though Botswana's per capita GNP, which according to World Bank estimates stood at over $900 in 1982, places it among the top ten developing countries in sub-Saharan Africa, the country faces many development challenges in the years ahead[1.].

One crucial issue facing Botswana is that as a landlocked country, it is almost totally dependent on neighboring countries for basic transportation links to world markets. For largely historical reasons, the strongest dependence is on South Africa, from which Botswana derives the bulk of its imports, through which almost all of its exports are sent, and which has provided the overwhelming majority of investment capital in the modern sector of the Botswana economy.[2] This dependence has posed difficult choices for Botswana over the years in that as worldwide opposition to South Africa's policy of apartheid has increased, Botswana's ability to expand its international trade has been restricted. For these reasons, Botswana has maintained its membership in the South African Customs Union, or SACU (established in 1969), whose members consist of South Africa, Swaziland, Lesotho, and Botswana, while at the same time, participating in the South African Development Coordination Conference, or SADCC (established in 1979), whose purpose has been to enable neighboring countries to lessen their dependence on South Africa.

One indication of Botswana's trade dependence is the valuation of its national currency, the Pula. Though the value of Botswana's currency is based on a basket of international currencies, because of its dependence on South Africa, the South African Rand constitutes an important weight in determining the value of the Pula. While the weighting system in many ways represents an efficient way to avoid currency price distortions, because Botswana's trade mix differs from that of its dominant neighbor, the choice of currency weights has not eliminated the possibility of market-based currency price distortions, a problem that carries some potential for bias in terms of energy policy alternatives.

Botswana's potential for economic development is relatively high. Even though population growth rates are rapid, because of its low population density, the country has not yet experienced some of the physical constraints found in other developing countries with similar climates and natural resources. Chief among Botswana's economic potential are its export earnings potential from minerals, notably diamonds, coal, nickel, and copper, as well as its potential earnings from agriculture, notably livestock and derivative products. Added to these factors is that Botswana's external debt has remained relatively low, reflecting not only a trend of frequent balance of payments surpluses, but also prudent government budgeting decisions that have kept public debt well under control. What should be kept in mind, however, is that Botswana does face serious problems regarding the development of its transportation sector, regarding the development of an educated and skilled labor force, as well as in terms of creating opportunities for sustainable economic growth in the years ahead. For these reasons, Botswana policymakers have continued to pursue strategies that facilitate the process of development, a key element of which is multi-year national development planning. At present, Botswana is in the process of shaping its sixth national development plan, with expected rates of growth in per capita real Gross Domestic Product at approximately two percent per year under its base case scenario.

B. **Energy in the Botswana Economy**

As with other developing countries in Africa, Botswana has a relatively high dependence on fuelwood energy in comparison to conventional fossil fuels. Table I provides a profile of the role of wood energy in Botswana's energy mix, based on commercial energy estimates made by a 1984 World Bank energy sector survey, and on wood energy consumption estimates made by a study just completed in early 1985 by the Overseas Development Administration[3.]. As can be seen from the historical and projected figures, as well as in Figure 1 and 2, wood accounts presently for approximately one quarter of Botswana's aggregate energy consumption. At the same time, although absolute consumption of wood is likely to increase, the woodfuel share of aggregate energy is expected to decline, reflecting a shift in energy demand to largely fossil fuels as the level of income and the degree of urbanisation rise over time.

Coincident with the projected decline in the role of fuelwood is a decline in the estimated degree of dependence on imported energy, along with a decline in the projected degree of aggregate energy intensity, or the ratio of aggregate energy to Botswana's Gross Domestic Product. At present, Botswana imports virtually all of its petroleum and natural gas energy, and imports both coal and electricity on a substantial scale. The primary source of this imported energy is South Africa, even though some of Botswana's petroleum and natural gas imports from South Africa may be derived from non-South African suppliers[4.]. In any case, in the event that South Africa experiences a contraction of its supplies of fossil fuels, as did occur during the OPEC oil embargo during the 1970's, Botswana remains vulnerable to an energy supply shock for the forseeable future.

Botswana's vulnerability to disruptions in its supplies of imported fossil fuels is the principal reason why policymakers have looked into ways of increasing national energy independence. Since Botswana has no known supplies of petroleum or natural gas, increasing energy independence involves a combination of policy actions. One is to foster a more efficient use of imported fossil fuel resources, a process that is already occurring since even at relatively untaxed levels, natural gas and refined petroleum product prices in Botswana are already at comparatively high world levels[5.]. Another approach is to foster alternative sources of fossil fuel imports, which at present is limited by the relatively high costs of transport in Botswana as well as by logistical issues in transporting imported energy from such far away locations as the Gulf Oil refinery in

Cabinda, or across rail routes as far away as Dar es Salaam. A third approach is to accelerate the development of Botswana's own coal resources, which are substantial, thereby eliminating the demand for imported coal, even though the issue of dependence on imported supplies of natural gas and refined petroleum products would remain. Finally, Botswana could engage in a costly effort to develop synthetic fossil fuels, much as South Africa has tried to do with its synthetic fossil fuel plants at Sasolburg, but this appears so far to be so expensive a solution that it would not be worth the effort except in the most extreme circumstances.

Beyond the quest for fossil fuel independence, Botswana's other principal energy policy issue has been what action to take with regard to the current and projected dependence on fuelwood energy resources. The issue here is not one of dependence on imported supplies of energy, as Botswana is virtually self-sufficient in fuelwood supplies. Rather, the issue is to what extent accelerating consumption of fuelwood poses a threat to environmental stability as well as to the distribution of income between Botswana's relatively affluent urban consumers and the relatively poor rural communities for whom fuelwood constitutes a primary if not sole source of energy. Although fuelwood accounts for only one-quarter of Botswana's aggregate energy consumption, it remains far and away the premier energy resource for the typical Batswana. The reason for this somewhat lopsided dependence is that fuelwood constitutes the principal energy resource used by the residential sector of the economy, accounting for over ninety

Table 1

Botswana Gross Energy Demand Projection

(Base Case - Tonnes of Oil Equivalent)

A. **Basic Aggregates**:	**1982**	**1985**	**1990**
1. **Gross Demand by Resource**:			
Wood	158327.00	174160.00	202615.00
Coal	252600.00	327600.00	534800.00
(Imports)	22500.00	24100.00	30000.00
Electricity	20500.00	45000.00	45000.00
Petroleum & Gas	148700.00	163100.00	199100.00
Total, Tonnes of Oil Equiv.	580127.00	709860.00	981515.00
2. **Imported Energy Share** (%):	33.04	32.71	27.93
3. **Population**	996,504	1,096,2721,309,072	
4. **1985-86 Pula Real GDP**, in millions	1197.77	1469.442124.85	
5. **Aggregate Energy Intensity**, in Kg Oil Eq. per Pula	.4843	.4831	.4619
6. **Per Capita Aggregate Energy Consumption, in TOE / yr.**	.5822	.6475	.7498
a. In Kg. Oil Eq. per Day	1.60	1.77	2.05

B. **Sectoral Demand for Energy**

(Delivered Energy Basis, in %)

Mining	40.10
Transport	14.30
Government	2.30
Manufacturing / Commerce	7.00
Water Pumping	4.10
Residential	32.20
Total	100.0%
Aggregate Quantity, TOE	590,292.84 TOE

C. **Composition of Residential Energy Demand** (1985 only):	**1985** % Aggregate En.Demand	**1985** % Sectoral En.Demand
Wood	29.70	92.20
Coal	1.00	3.20
Petroleum(&Gas)	.60	1.90
Electricity	.90	2.70
Total	32.20%	100.0%
Aggregate Quantity, TOE	188,893.71 TOE	188,893.71 TOE
Aggregate Quantity,T.Wd.Eq.	539,696.31 TWE	539,696.31 TWE

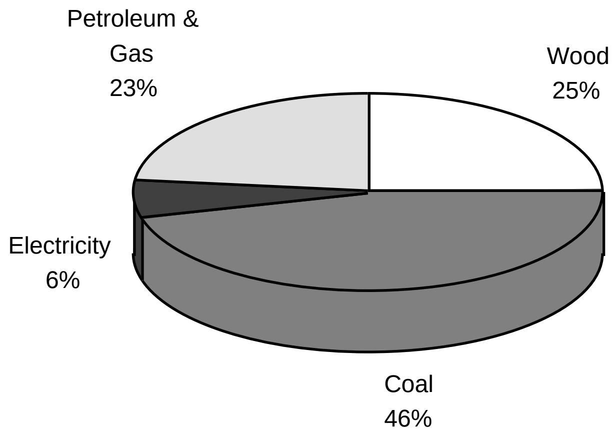
1. **Residential Wood Energy Demand**(Domestic & Commercial)	**1985**
a. tonnes / yr(539,696.32x.922)	497,600 tonnes
b. in tonnes per capita / year:	.4539 tonnes / yr per capita
c. in kg. per capita per day:	1.24 kg. / day per capita
d. in tonnes per HH per year:	2.64-2.72 tnn. per year per HH
e. in kg. per HH per day:	7.23-7.46 kg. / day per HH

Source: NDP-VI, IBRD Energy Sector Report (Sept. 1984), ODA, Rural Energy Survey (March 1985).

Figure 1

Botswana Gross Energy Demand by Resource

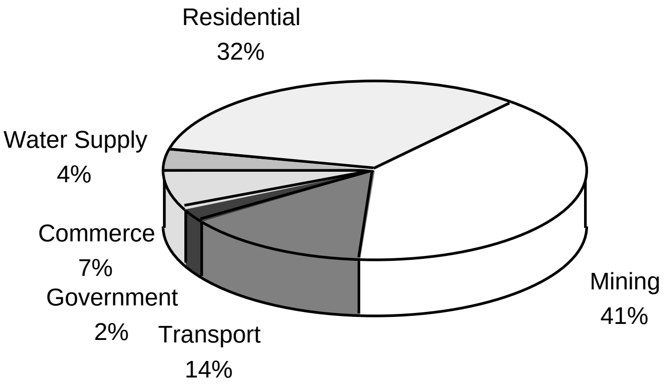
(1985, in Tonnes of Oil Equivalent)



Source: NDP-VI, IBRD Energy Sector Report (Sept. 1984),
ODA, Rural Energy Survey (March 1985)

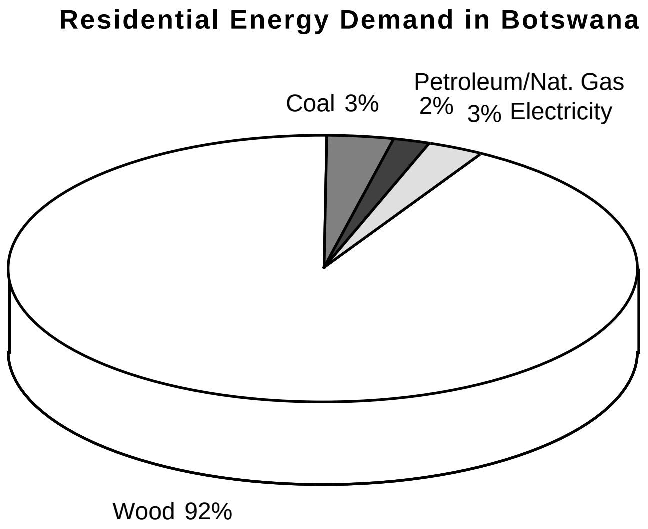
Figure 2

The Sectoral Demand for Energy in Botswana



Source: NDP-VI, IBRD Energy Sector Report (Sept. 1984),
ODA, Rural Energy Survey (March 1985)

Figure 3



Source: NDP-VI, IBRD Energy Sector Report (Sept. 1984)
ODA, Rural Energy Survey (March 1985)

percent of all residential energy consumption in 1985. Although such dependence by itself would not appear to constitute a problem for an economy in which the role of fuelwood is expected to decline over time, because the residential share of fossil fuel consumption is expected to rise over time as urbanization and economic growth proceed, any potential disruption in the supply of fossil fuel energy would automatically have an adverse impact in terms of an increased demand for fuelwood supplies and its attendant increase in price. Moreover, even in the event of no disruption in the supply of imported energy, as long as population growth continues to expand at its current rates, pressures on fuelwood supplies are bound to increase. As a result, accelerated deforestation could aggravate environmental stability, creating the conditions for prolonged drought and desertification in a country where water supplies are already a major issue. It is precisely for such reasons that Botswana policymakers decided several years ago to promote research and development efforts into alternative renewable energy technologies, through the creation of such institutions as the Botswana Renewable Energy Technology Project.

Because the estimates of Table I play such an important role in the analysis of specific renewable energy technologies, it is important to point out the derivation of wood energy end uses. As can be seen, the total estimated consumption of fuelwood in 1985 is estimated at just under 500,000 tonnes. This estimate has been divided by the

1985 estimated level of population of one million people to obtain the amount of per capita annual wood energy consumption. In turn, a daily per capita wood energy consumption estimate has also been computed, which is useful for purposes of comparison with estimates from the village and urban energy surveys that have been conducted over the past year. Finally, depending on one's estimate of household size, estimates of annual and daily household consumption of wood energy have also been computed for purposes of analysis in this report.

C. **The Role of Renewable Energy Resource Technologies**

Given the importance of fuelwood to Botswana's aggregate energy mix, policymakers confront two basic choices. One is to accelerate the replacement of fuelwood energy supplies, while the other is to accelerate a shift into alternative renewable energy technologies as well as into energy conservation technologies. It is worth noting at this point the conclusion arrived at by the ODA in their recent study of rural energy consumption, namely, that in the aggregate, Botswana does not at present appear to confront shrinking wood energy supplies, but that in the densely populated southeastern portion of the country, a fuelwood crisis is indeed at hand, and that the appropriate solution is to accelerate the development of village woodlot growing schemes around relatively deforested urban areas as the best solution to the problem. The difficulty with this proposal is that while a solution to the wood energy problem is likely to involve elements of both supply and demand, supply-side strategies elsewhere in Africa have proven to be far more expensive than originally envisaged, if for no other reason than the difficulty in selecting readily marketable fast growing species as well as finding ways to guarantee the property rights essential to their growth. At this point, what can be said is that the case for accelerating wood energy supplies depends partly on the economics of wood conserving energy technologies. Since there is an economic case for wood energy conservation technology, before any policy decision is made, one should weigh carefully the relative costs and benefits of each of these two strategies.

Table 2
Socio-Economic Aggregates from Surveys of Wood-Using Communities in Botswana

Community	Survey Author, Date	Daily Per Capita Wood Consumption in Kg.	Population (1981 Census)	Mean Distance Travelled to Obtain Fuel-Wood	Price per Kg.in thebe	Wealth Index
Bobonong	(ODA, 1985)	1.19	4,711	4.8 km.	2.3	36
Ditshegwane	(OKi, 1984)	1.30	821	3.5	n/a	11
Gaborone	(Gay, 1985)	1.12	59,657	45.0	8.9	73
Good Hope	(ODA, 1985)	1.40	841	5.9	3.0	51
Lecheng	(ODA, 1985)	1.36	1,026	3.5	4.5	15
Lobatse	(Gay, 1985)	1.63	19,034	26.6	14.6	75
Mahalapye	(TEAM,1984)	1.33	20,712	10.0	2.7	41
Mmankgodi	(ODA, 1985)	1.58	2,600	3.9	7.0	27
Masunga	(ODA, 1985)	2.13	1,193	2.8	3.0	26
Molepolole	(Gay, 1985)	1.00	20,565	30.0*	13.7	61
Palapye	(Gay, 1985)	1.65	9,593	4.0	14.3	54
Selibe-Pikwe	(Gay, 1985)	1.81	29,469	15.0*	28.5	56
Serowe	(Gay, 1985)	1.47	23,661	51.0	12.2	36
Shoshong	(Oki, 1984)	0.99	4,600	7.5	2.5	27

Source: John Gay, *Urban Energy Survey, in Serowe, Palapye, Molepolole, Selibe-Phikwe, Lobatse, and Gaborone*. (Burlington, Vt.: ARD, Inc., under AID contract 633-0209-C-00-1024-00, January 1985). Energy Planning Associates, *A Study of Energy Utilization and Requirements in the Rural Sector of Botswana*, prepared for Overseas Development administration(ODA), in association with International Forest Science Consultancy. (London: Energy Resources, Ltd., May 1985). HHC TEAM Consultants, Inc., *Mahalapye Upgrade Feasibility Study*, vols. I and 2. (Calgary, Alberta, Canada: HHC TEAM Consultants, Inc., for MLGL, June 1984)

The wealth index is based on data from the 1981 national population and housing census. Using a methodology devised by the ODA study (pp. 41-42), the wealth index consists of five components equally weighted:

a. the percentage of households owning cattle;
b. the percentage of households with a pit latrine (or better);
c. the percentage of households whose houses had permanent roofs (i.e. concrete/brick, asbestos, iron/zinc./tin);
d. the percentage of households whose houses had permanent walls (i.e., stone/brick, asbestos, iron/zinc/tin); and
e. the percentage of households whose houses had permanent floors (i.e. stone./tile/cement, wood).

Assigning one point for every five percent of households with each of these characteristics yields a theoretical range between 0 and 100. In the ODA study, the actual index ranged from 8 to 67.

* Approximations by BRET staff.

A clearer understanding of the role of fuelwood in Botswana's energy mix can be gained by reference to the several energy surveys that have been conducted in Botswana over the past year and a half. Two of these have been done under BRET auspices, one a survey of six urban areas and the other a survey of two rural ones, while a third survey has been done by ODA on five rural communities. In addition, data from a feasibility study on the upgrading the infrastructure of the community of Mahalapye has also been included. Key socio-economic aggregates from these surveys are reported in Table II. In general, they suggest the kind of dynamic demand relationship outlined in the preceding section, namely, that as urbanisation and income levels advance, fuelwood consumption increases. However, one constraint to accelerating fuelwood consumption is the fuelwood price as well as the mean distance travelled to obtain fuelwood, whether for direct consumption or by open market purchases. As far as projected demand is concerned, what one would expect to occur is that at some point, higher real prices of fuelwood along with higher real incomes would lead households to shift their demand for residential energy away from fuelwood to a commercially competitive substitute such as paraffin, natural gas, or electricity. Unfortunately, the limited size of the survey samples as well as differences in survey methodologies have made it difficult to derive a useful estimating equation that could be used to sort out these relationships in a more systematic fashion.

Taken together, Botswana's energy options for the forseeable future include the need to address the rising shortage of fuelwood in its largely urban areas. To the extent that wood energy conservation can play a role depends on the economics of alternative wood energy conservation technologies, to which we now turn.

II. Methodology

A. Introduction to Financial and Economic Analysis

The methodology used to assess the renewable energy technologies covered in this report is benefit-cost analysis. Benefit-cost analysis is used because each of the respective technologies represents an investment in a durable good with a multi-period lifetime. For this reason, valid comparisons and conclusions can be drawn only if one takes into consideration the life cycle of the technology rather than its initial capital cost. Although many of the concepts used in benefit-cost analysis may be familiar, in the sections that follow, all of the basic steps and tools used in the analysis are reviewed so that one can readily interpret the results.

Throughout this report, two levels of benefit-cost analysis are employed. One, financial analysis, pertains to the economic viability of investment decisions from an individual household and market producer perspective. Strictly speaking, financial analysis enables one to evaluate investment decision based purely on private market prices, independent of any government action. On the other hand, economic analysis, which also uses the tools of benefit-cost analysis, incorporates the impact of market price distortions caused by imperfections in the structure of markets, including due allowance for government tax and spending decisions. Here, the perspective is not that of the household and individual market producer, but society as a whole. Because terms such as net present value, internal rate of return, and benefit-cost ratio are common to both, it is important to distinguish wherever possible which type of evaluation is being applied. This differentiation is drawn not only within the text, but also in the tables. The tables also permit one to make side by side comparisons of the two approaches.

B. Fundamentals of Benefit-Cost Analysis

Regardless of the benefit-cost perspective that one uses, there are a several fundamental concepts that need to spelled out at the outset. The first pertains to consumption versus investment decisions. The key distinctions between a consumer good versus a capital good are durability and productivity. Renewable energy technologies are capital goods in that they share both of these attributes. They generally last for more than one year, and they are productive in the sense that they displace the consumption of a conventional source of energy. However, in order to make useful comparisons of whether a given technology is economic, one must take into account the valuation of future versus present costs and benefits.

Whether one is receiving a sum of income or paying a cost, any transaction that takes place in the future is by definition less important to the decisionmaker than one that takes place in the present. The way that one makes such inter-temporal comparisons is through use of a discount rate. A discount rate defines the decision-maker's intertemporal rate of time preference regarding the valuation of present versus future costs and benefits. Thus, if one has a five percent personal rate of discount, then if one is to be indifferent between a Pula's worth of income to be received today versus a Pula's worth of income to be received tomorrow, tomorrow's Pula must include a five percent premium, or interest payment. Unless this premium is attached to tomorrow's income, then the individual would prefer to consume the Pula today. This simple concept of time preference is the key to all capital investment decisions, be they undertaken by government or by individuals.

Let us expand the concept of discounting to an n-period example. In this case, we are looking at a stream of benefits that are payable in annual installments over a five-year period. Whether the annual payment stream is one Pula or X Pula per year, we can then calculate the present value for the stream of benefits as:

$$(1.)\qquad \text{PVB} = \frac{B_0}{(1+R)^0} + \frac{B_1}{(1+R)^1} + \frac{B_2}{(1+R)^2} + \frac{B_3}{(1+R)^3} + \frac{B_4}{(1+R)^4}$$

where R is the rate of discount, and B is the economic value of benefits in each time period. Although one could use continuous time to arrive at a present value calculation, because most financial institutions and most individual firms and households behave in a way that is consistent with discrete time valuation, it is this latter method that is used throughout the analysis.

To put equation one in a more compact form, we can use sigma summation notation to obtain:

$$(2.)\qquad \text{PVB} = \sum_{i=0}^{n} \frac{B_i}{(1+R)^i}$$

where n in the present example is 4. It should be noted that the benefit stream in the initial time period is not discounted even though the compound formula appears in the denominator, since any expression to the zero exponent has a value of one. As a result, the number of time periods in the compound discounting is one less than the total number of time periods for the whole benefit stream. The result is that by using a discounted value for each benefit for each time period, one has a consistent way to aggregate benefits that occur in a future time period with those that occur in the present.

A similar set of calculations is needed for the derivation of the present value of costs. Mathematically, the present value of costs that corresponds to the five-period example of equation one can be defined as:

$$(3.) \qquad PVC \;=\; \frac{C_0}{(1+R)^0} + \frac{C_1}{(1+R)^1} + \frac{C_2}{(1+R)^2} + \frac{C_3}{(1+R)^3} + \frac{C_4}{(1+R)^4}$$

where R is the same rate of discount as used in equation one, and C is the economic value of costs in each time period. Again, one can use sigma summation notion to obtain the present value of costs:

$$(4.) \qquad PVC \;=\; \sum_{i=0}^{n} \frac{C_i}{(1+R)^i}$$

where Ci is the cost in the ith time period, and all other notation has the same interpretation as in equation three. What equations three and four define is the present value of the costs of the technology over the lifetime of the technology. For this reason, this present value figure is also known as the life cycle cost of the good.

Given the choice of a particular discount rate, equations two and four enable one to derive two of the three basic measures that are used in the financial and economic analysis of this report. The first measure is the net present value, while the second is the benefit-cost ratio. To derive the net present value of an investment, one simply subtracts the present value of costs from the present value of benefits, i.e.,

$$(5.) \qquad NPV \;=\; \sum_{i=0}^{n} \frac{B_i}{(1+R^{i})} - \sum_{i=0}^{n} \frac{C_i}{(1+R)^i}$$

As long as the net present value is positive, then the investment decision is economic. In terms of the analysis used in the report, since decision-makers may differ depending on the technology and the associated attitudes toward time and risk, different rates of discount have been employed. These rates range from the government's own six percent to a thirty percent rate more appropriate to individual decision-makers to assess the economics of the various renewable energy technologies.

The reason for using different rates of discount is so that one can examine the viability of an investment decision from an individual financial perspectlve as well as from an economic perspective of society as a whole. When one is considering the financial viability of an investment from an individual market perspective, higher rates of discount that are comparable to what each individual would have to pay to acquire the necessary funds from a financial institution are appropriate. On the other hand, if one is examining the economic viability of an energy technology from society's perspective, then a rate more approximate to government's own rate of discount is appropriate.

A second measure used to assess investment decisions is the benefit-cost ratio. The benefit-cost ratio is the ratio of present benefits to present costs, which in terms of equations two and four is defined as:

$$(6.) \qquad \text{B/C Ratio} = \frac{\sum_{i=0}^{n} \frac{B_i}{(1 + R^i)}}{\sum_{i=0}^{n} \frac{C_i}{(1 + R^i)}}$$

Intrepretation of the benefit-cost ratio follows directly from the net present value measure. As long as the net present value of an investment is positive, the benefit-cost ratio will be greater than one, in which case the project is economic. In terms of a minimum level of acceptability, a zero net present value and a benefit-cost ratio of one can be used. Although household, individuals typically do not calculate benefit-cost ratios for purposes of making financial decisions, the logic of this ratio can still be applied.

In addition to the net present value and benefit-cost ratio tests, investment evaluation also relies on the use of an internal rate of return. In this case, rather than use an a priori specified rate of discount, one derives that rate of discount which yields a net present value of zero, or what is equivalent, a benefit-cost ratio of one. In terms of equations two and four, the internal rate of return is thus defined as:

$$(7.)\quad IRR = \left[\sum_{i=0}^{n} \frac{B_i}{(1+R)^i} - \sum_{i=0}^{n} \frac{C_i}{(1+R)^i} = 0 \right]$$

Interpretation of the internal rate of return is also straightforward. As long as the internal rate of return is greater than or equal to the opportunity cost of investment resources, then the project may be considered economic. Thus, if the government's rate of discount is six percent and if the the internal rate of return is ten, then the project is economic from the government's, and thus society's, perspective. On the other hand, if the prevailing commercial rate of interest is twenty-five percent, if the investment decision carries an expected thirty percent internal rate of return, then it is economic to the individual.

The difficulty with the internal rate of return is where the discounted stream of benefits and costs may have negative values in more than one time period. In such cases, the derivation of the internal rate of return, which is based on the solution to an n-order polynomial equation, will yield more than one root. Although there are ways to avoid such polynomial ambiguity, none is entirely satisfactory[4]. For this reason, while it may serve as a useful first approximation to derive the internal rate of return of a project, use of the net present value and corresponding benefit-cost ratios is considered as a far more satisfactory approach. However, in terms of the present analysis, because polynomial ambiguity is not a major problem, all three measures are employed.

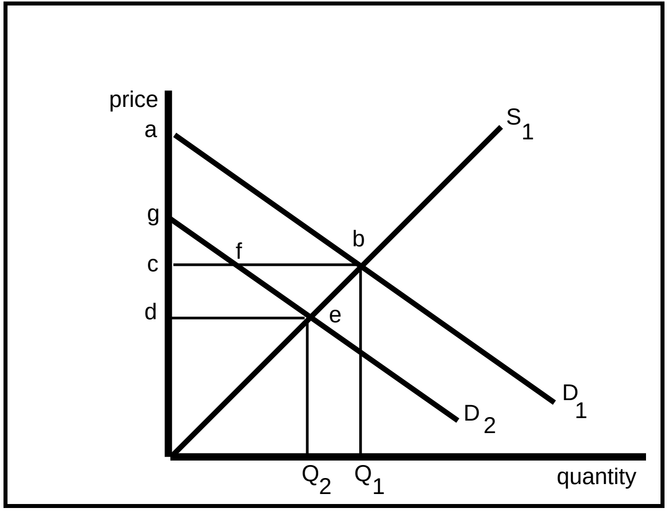
Derivation of investment evaluation measures is computationally straightforward. The major difficulty in assessing an investment project is in terms of the measurement of benefits and costs, as well as in the selection of an appropriate rate of discount. It is therefore worth discussing some of these measurement issues as they arise in the context of the evaluation of renewable energy technologies.

C. Measurement Issues in Benefit-Cost Analysis

In the analysis of any investment decision, if there is uncertainty or potential bias regarding the valuation of costs and benefits, the appropriate way of examining the impact of these factors is through sensitivity analysis. What sensitivity analysis enables one to do is to differentiate between the financial and economic assessment of an investment project. What this means is that while the financial appraisal of a project takes into account only prevailing market prices, an economic assessment incorporates the impact of potential market price distortions. For this reason, the economic appraisal of investment projects has also come to be known as social benefit-cost analysis. Because there are several sources of potential uncertainty and bias in the assessment of renewable energy technologies in Botswana, the methodology used to address them in this report is spelled out here.

Figure 4

Measuring Changes in Social Welfare



In the assessment of investment decisions, reference has already been made to life cycle costs. Despite their rational simplicity, life cycle costs do present some measurement difficulties. One of these is the capital cost itself. Here, one potential source of distortion lies in whether market prices provide an adequate measure of the initial capital cost. For example, if imported inputs constitute a significant proportion of the capital cost, and if there are foreign exchange rate distortions, then there will be a distortion of the true cost of the capital resource to society. In this case, (which, it should be pointed out, also arises with respect to recurrent costs), the appropriate method of adjustment is through use of shadow prices. A shadow price is a nonmarket price that more accurately reflects the true cost or benefit of a transaction to society as a whole. For Botswana, government policymakers have traditionally used a shadow foreign exchange rate of 1.1, implying that the Pula is overvalued by ten percent. In terms of the assessment of the specific projects, the imported materials and tools used in the construction of the BRET metal stove constitute the largest source of this type of error. In the sensitivity analysis, several tests were conducted using a range of shadow foreign exchange rates in order to account for this bias.

The social cost of labor constitutes another potential source of bias in the measurement of investment project costs. The social cost of any resource is the private individual cost plus any external cost that is borne by other members of society. Here, the issue is one in which the market prices of skilled and unskilled labor may not accurately reflect their opportunity cost to society. What has traditionally been the practice in Botswana is to use a .5 shadow price adjustment factor for unskilled labor, allowing implicitly at least for the possibility of a premium shadow price adjustment for skilled labor. Although shadow prices for labor are an important issue in the case of some investment decisions, because all of the renewable energy technologies examined in the present report use relatively skilled labor, no adjustment was made for potential labor market price distortions.

The level and frequency of recurrent costs is another area of potential bias in investment project appraisal. Recurrent costs consist of two basic components, namely, annual operating and maintenance costs, as well as periodic parts replacement costs. When one is evaluating a relatively new investment technology, because so little operating experience is available regarding these recurrent costs, one has to make some assumptions regarding the frequency and intensity of these costs. Moreover, one must also allow for the fact that the replacement cost of a part, which is estimated in today's prices, may also experience an increase in its real, or inflation adjusted, cost over time. In the present analysis, relatively liberal assumptions regarding the frequency and rate of increase in real prices have been used so that one does not underestimate the impact of these costs on the economics of specific technologies.

On the benefit side, there are also several measurement issues that arise in project appraisal. One is whether market prices provide an adequate measure of the social benefits of a project. In the case of fuelwood conserving energy technologies, because a significant proportion of fuelwood is gathered rather than bought through established market channels, the market price of fuelwood may not reflect the social benefit of a fuelwood conserving technology to society. In all cases, the social benefit of any good consists of the private benefits to individual consumers as well as the external benefits to other members of society. Because external benefits may be at least as significant as private ones, one should attempt to include them in the assessment of any investment project.

One way to address the issue of social benefits is again through use of appropriate shadow prices. As an example, since fuelwood is a quasi-common property resource, the social price of fuelwood is the market price plus some premium that reflects the replacement cost to society. In the present report, several estimates of the price of fuelwood have been used in order to allow for this type of distortion.

Investment appraisal is also affected by the value one attaches to the physical quantity of benefits. As in the case of the measurement of recurrent costs, the potential benefits of an investment decision depend ultimately on the typical rates at which the technology is used. One can not simply use a controlled laboratory test as the basis of the benefits of a project, as this is likely to overstate the typical rates at which a technology will be used. in the present analysis, because of uncertainty regarding ultimate rates of use of specific technologies, allowance has been made for varying degrees of benefits, using laboratory performance standards as an upper limit.

A third issue in the measurement of investment benefits is whether all other conditions remain equal, i.e., the *ceteris paribus* assumption. Here, the problem is that the adoption of a particular technology may bring about changes in the production and consumption of other resources, at both an individual and at an aggregate economic level. On an individual level, if such changes do occur, then the appropriate way to account for this shift is to reduce the estimate of potential benefits by the corresponding degree of net change in benefits. This involves the use of initial prices which are then multiplied by the corresponding net changes in quantities.

On an aggregate level, the estimation of benefits becomes more complex. For example, if society as a whole adopts a particular investment technology, for each period over the life cycle of the project, the demand for the resource that the technology displaces will have been reduced by a specific amount. Such a shift is illustrated in Figure 4, denoted by the decline in demand from D1 to D2, while S1 denotes the supply schedule of the resource that the investment technology displaces. Theoretically, the social value of benefits from any investment project is the change in the sum of Producer and consumer surplus. The initial level of social welfare consists of the sum of producer and consumer surplus, which is represented respectively as the triangles ocb and abc. Since the investment project enables one to forego a portion of the demand for a good, as in the shift from D1 to D2, then the benefit to society consists of the opportunity cost, or avoided cost, of the investment technology, i.e., the difference in consumer and producer surplus created by the shift between D2 and D1 The benefit of the investment technology would thus consist in the increase in producer and consumer welfare, denoted here by the trapezoid abeg. However, this estimate is based on c, the price of the resource that society would have to pay if it did not adopt the particular investment technology rather than d, the price that it would pay for what it continued to demand of the resource following the adoption of the technology. The potential bias that arises because of differences in the price of the good whose demand has shifted is thus the triangle fbe. Obviously, whether this bias is significant depends on the shape and position of the supply curve.

Although the use of consumer and producer surplus is the correct method for the assessment of investment (and consumer) decisions, accuracy in the measurement of social welfare depends crucially on a clear specification of the corresponding demand and supply curves. In the case of renewable energy technologies in Botswana, because of limitations in the data with which to estimate demand and supply relationships, the concepts of consumer and producer surplus have not been employed. Instead, measurement of changes in social welfare has been based solely on changes in the respective quantities of the energy savings available from the adoption of a particular renewable energy technology multiplied by the initial estimated price of the conventional energy resource.

One final issue involved in the assessment of investment decisions is the choice of an appropriate rate of discount. Although the government of Botswana traditionally uses a six percent rate of discount, because potential consumers of specific energy technologies may well be households, differences in individual versus social rates of time preference may differ substantially. The principal reason for this divergence is the level and distribution of risk. Clearly, society as a whole may be in a position to absorb a much greater degree of risk than could an individual alone. For this reason, individual rates of discount tend to be higher than for society alone. The way that these divergences have been incorporated into the present analysis is to utilize an array of discount rates, starting from the government's own six percent rate, with progressively higher rates to reflect the risk and time preferences of individual households.

D. Cost-Effectiveness versus Cost-Benefit Analysis

In many investments, the presence of external costs and benefits may be so pervasive that individual ones become insignificant. In this case, for an investment that may be economic, one is looking at a quasi-public or pure public good. In the case of a relatively pure public good, the issue is thus not one of measuring the immediate benefits in a directly quantifiable form, but one of finding the most cost-effective way of providing the good. The analysis to be used in such circumstances is thus known as cost-effectiveness analysis.

In the context of Botswana renewable energy technologies, there is a readily distinguishable classification of the two types of technologies. Any technology that is suitable to individual households or individuals is classified as a domestic energy technology. Examples of such technologies include the BRET stoves the retained heat cooker, and the batch solar hot water system. On the other hand, there are institutional technologies for which the benefits are so diffuse that no single individual would be willing or able to pay for them directly. Examples of such institutional technologies in Botswana include photovoltaic lighting and refrigeration systems for rural schools and clinics, as well as alternative community-based water pumping technologies such as diesel, windmill, and photovoltaic systems. Such public goods are provided solely by government units, be they at the community, regional, or national level. As a result, the decision on how much of society's resources to devote to the production of such investment resources depends exclusively on the political allocation of tax and borrowed resources, leaving for economic analysis only the determination of cost-effective alternatives by which one could obtain an equivalent level of output.

The assessment methodology for institutional energy technologies utilizes several of the concepts already defined in section B. Since one is not concerned with the direct measurement of benefits, costs alone form the basis of cost-effectiveness analysis.

The first step in cost-effectiveness analysis is the derivation of the life cycle, or present value of costs of a particular investment technology. Thus, with all of the caveats pointed out in the preceding section, the relevant measure is equation number four. However, since one is interested in a costeffective comparison of alternative ways of producing a given output, one must convert the life cycle cost of an investment technology into an annualized unit cost. An annualized unit cost incorporates into today's prices, the unit cost of producing a given level of output, including some fraction of those recurrent costs that the technology will impose over its economically useful lifetime.

The derivation of an annualized unit cost is based on the product of the present value of costs times a capital recovery factor, which is then divided by the annual level of output from the technology, Mathematically, the annualized unit cost is thus defined as:

$$(8.)\quad AUC = \frac{\left[\sum_{i=0}^{n} \frac{C_i}{(1+R)^i}\right] x \left[\frac{R(1+R)^n}{(1+R)^n - 1}\right]}{Q_i}$$

where: AUC = annualized unit cost,
n = lifetime number of periods of investment project,
Cj = cost in the i th time period,
R = rate of discount,
Qj = annualized quantity of output.

In lieu of the derivation of the annualized unit cost based on equation eight, one could also derive an annual unit cost by amortizing the initial capital cost of an investment technology and implicitly assigning some value of the future recurrent costs to the initial year. Although this method provides a first approximation, it is generally not as accurate as the method specified in equation eight because there is no clearly defined basis for arriving at the present value of the future recurrent costs. Thus, the life cycle approach is the preferred method.

Although cost-effectiveness analysis is as computationally straightforward as in the case of cost-benefit analysis, there are several measurement issues that need to be considered. This is especially so in the case of renewable energy technologies where the physical output of a technology may be variable, as in the case of water. The reason why this becomes significant is that if one is to make cost-effective comparisons on a risk-equivalent guaranteed supply, then in the case of a variable wind regime or in the case of variable insolation, one must incorporate into the design of a project a corresponding storage system that provides a given quantity of output.

The optimal storage size of a renewable energy technology depends on the, equivalent level of output that would be provided by a potentially cost-effective competitive technology. A convenient way of incorporating the annualized unit storage cost into equation eight is to utilize the framework of an inventory-sales model . Without going through the specific derivation of this model7, we can utilize the results to portray the annualized unit storage cost component that should be added to the annualized unit production cost of equation eight. Mathematically, if a storage system has a fixed annual cost of Pula per year, and if variations in the delivered quantity of output require that one store D physical units per year relative to the production of Q units per year, then the per unit annualized storage cost of the output can be defined

$$(9.)\quad USC = K = \frac{2AQ}{D^2}$$

Thus, if the numerator of equation eight can be defined as , then the annualized unit cost of a production plus storage system can be defined as:

$$(10.)\quad AUC_{P+S} = \frac{J}{Q_i} + \alpha(K)$$

where alpha represents that fraction of a year that a unit of output remains in storage. While there are many refinements that one could add to the preceding methodology, in light of the data available for the specific renewable energy technologies examined for Botswana, only the steps covered in this discussion have been considered.

III.BRET Stoves

A. Conceptual Issues in the Analysis of BRET Stoves

Given the importance of wood energy to Botswana's aggregate energy balance, any technology that reduces wood energy consumption is beneficial in a number of fundamental ways. As pointed out in the introduction, one of these is that wood energy conservation provides a fundamental benefit to the environment. Another is that since poorer families are likely to be more dependent on wood energy than the rich, any technology that conserves wood is likely to provide a redistributive benefit to the poor. Yet apart from these broad based socioeconomic benefits, the ultimate test of the wood energy conservation argument is whether, and at what price, a wood energy consumer would be willing to pay for wood energy conserving technology, be that a metal stove, a wonderbox, a solar hot water heater, or some other system.

On an individual basis, the benefit to a potential consumer of a wood conserving technology can be measured in terms of the amount of wood energy saved. The value of these wood energy savings can be broken into two constituent parts. One is the value of the fuelwood purchased. This benefit applies basically to urban wood energy consumers whose consumption is determined by fully functioning wood markets. For these urban consumers, the value of wood energy saving is the price times the quantity of fuelwood saved.

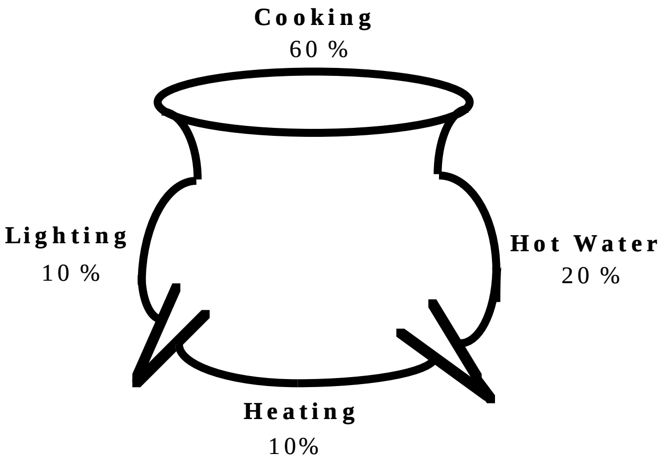
The other benefit, which occurs in rural areas, is the value of wood energy collection time. Here, a smaller proportion of wood consumption takes place through open market purchases since individual households devote a portion of their time to gathering fuelwood from open, or "free" (to the individual, as opposed to the community) wooded areas. For such rural wood energy consumers, the value of wood energy saving is the quantity of time saved multiplied by the opportunity cost of that time, i.e., the amount of income that one could earn in the absence of engaging in fuelwood collection. Needless to say, for many rural communities, households promote economic (as opposed to wood energy) efficiency by assigning fuelwood collection tasks to a family member whose opportunity cost, in market price terms, is relatively low, in which case, the benefits from a wood energy conserving technology would be perceived by the household to be relatively small unless one places a premium value on leisure time.

Another benefit of a wood energy conserving technology is that it reduces the time needed to perform the tasks that one would undertake with a traditional open fire system. Here the measurement issue is more problematic, as a simple illustration will point out. As can be seen in Figure 4, an open fire system in which a household uses a traditional three-legged pot performs at least four distinct functions, namely, cooking, heating hot water, lighting, and space heating. The "social value" of an open fire can be thought of largely as the combined output from an open fire system that is providing both light and heat. Yet most users of an open fire system frequently combine the "social value" function with cooking and hot water. In theory at least, the proportions of wood energy consumption devoted to these roles ought to be readily measurable. However, none of the surveys identified in Table 2 provided a satisfactory estimate of these functions. For this reason, the proportions specified in Figure1 should be thought of as approximations of wood energy functions.

One additional conceptual issue in wood energy conserving technologies is the thermal efficiency of an open fire system. Evidence from studies throughout Africa suggests that open fire thermal efficiencies can range anywhere from five to twenty-five percent, although typical efficiencies are lively to lie between ten and twelve percent. With such a varied range of thermal efficiencies, estimating the value of wood energy conserving technologies is a difficult task. The problem is that for a household that relies on a traditional open fire system, as long as the historical thermal efficiency is low, one of the first things that the household is likely to do in response to increasing scarcity of fuelwood is to make improvements in open fire thermal efficiency. This can occur through any number of ways. One simple way is to make an open fire in a location with a windbreak so that a higher proportion of the wood energy is captured for such principal uses as cooking and hot water heating. Another change is to place tin cans (and/or fired clay pots) filled with water next to a three legged cooking pot so that one can cook and heat water simultaneously. A third is to recess the open fire cooking area, thereby creating a stove-like environment. Of course at some point, as the number of hot water containers expands around the cooking pot and as the fire area is recessed, one eventually loses some of the light provided by the open fire system. Yet even with an open fire system, one might still maintain use of an open fire system by a greater use of candles or a paraffin lamp before one makes a shift to a stove technology. Despite these uncertainties, the approach used in the present analysis is based on assumed thermal efficiencies of open fire systems of between ten and twenty percent.

Figure 5

End Use of Residential Wood Energy



One additional issue is that the adoption of a wood energy conserving technology such as a metal stove may also increase the demand for substitute lighting. The reason for this is that unless the stove has an open door (which reduces the potential wood energy savings) a household forsakes the lighting function of the open fire system even as it gains in terms of the amount of fuelwood saved for cooking and hot water. although the heating function would remain unaltered, (or even improved if the metal stove is a good conductor that absorbs a significant proportion of the rejected cooking and hot water energy), it is thus possible that a stove using-household may increase its use of substitute lighting energy, thereby offsetting some of the potential wood energy savings.

Taken together, the way that these considerations are accounted for in the analysis of the BRET metal stove is to treat potential improvements in open fire thermal efficiency as equivalent to a reduction in the potential magnitude of wood energy savings. Obviously, if one had a more precise measure of how the thermal efficiencies of Batswana open fire systems vary in response to fuelwood scarcity, one could then assign a much more precise value to the potential of fuelwood savings from the adoption of a metal stove, or other wood energy conserving technology.

B. **Summary of BRET Metal Stove Production Experience**

Following the development of some thirty-three prototype metal stoves by BRET technicians, four production models have evolved, the B Model, the Super B, the Delta 3, and the Delta 6. The B and Super B are somewhat earlier versions, while the Delta 3 and 6 models are more recent. The Delta models differ from the B's in that they are simpler to produce. Apart from this difference, what distinguishes the models from each other is that the B and Delta 3 are designed for cooking with three legged pots ranging in numbers from one to three, while the Super B and Delta 6 can handle three legged pots with up to a number six capacity.

A summary of BRET stove production involving the B, Super B, Delta 3, and Delta 6 models for the period March 1984 through May 1985 is illustrated in Figures 5 and 6. During that period a total of 2,545 stoves were produced, most of which took place toward the end of 1984. Of the four BRET models, half of the production has been of the Delta 6, followed by the Delta 3, the B Model, and the Super B, respectively.

Production of stoves has taken place under two basic kinds of production modes, one being artisans in Gaborone and Molepolole, and the other being plant manufacturing in Gaborone. BRET chose these two production environments for two basic reasons. One was to determine if there would be significant production cost differences between artisan and plant manufacturing systems as well as to examine the impact of these alternatives on local employment. The other was to examine whether transportation between production and market sites would represent a significant proportion of stove costs, particularly in that the largest potential market for the stoves would be in the largely urbanised communities in the southeast area of the country. As will be shown shortly, there do not appear to be substantial production cost differences, nor do transport costs appear to constitute a significant proportion of total delivered unit costs.

C. **Estimation of Stove Unit Costs**

In order to arrive at reasonable estimates of the economics of the BRET stove,careful account must be made of both costs and benefits. The principal categories of costs are summarized in Table 5. For purposes of analysis, three levels of unit costs were estimated. One is the basic Production cost_Included in the basic production cost are the production materials, labor, material transport, warehouse transport, production tool costs, and the training cost of production. To derive the estimates for each type of BRET stove, current cost figures for each of these components were estimated by BRET staff. The Comparative Materials Cost for each type of stove is summarized in Table 3, based on the production specifications outlined by BRET staff. As to tools, although someone who might be producing BRET stoves could well already have the necessary tools, one should include an estimate of tool costs for their depreciation value. The technique used to depreciate the tools is straight-line depreciation, with lifetimes for each tool estimated from typical usage rates. In terms of material transport and warehouse transport, estimates of these costs were based on Government of Botswana per kilometer reimbursement rates of 30 thebe per kilometer for all weather roads, and 42 thebe per kilometer for unpaved ones, based on light utility vehicle use. The training cost component, which is more like a fixed cost, was estimated from BRET staff training costs for artisans involved in the production of the BRET models.

The second unit cost estimate, which is also the one used most frequently in the analysis, is the delivered Production cost, which is the figure used for purely financial analysis. This figure consists of the sum of the basic production cost plus inventory and transport distribution costs. Although these inventory and distribution costs have been borne by BRET, estimates have been based on both actual inventory storage payments, as well as on the corresponding Government reimbursement rates for transport in order to arrive at what inventory and distribution costs would be in a private production environment.

The third unit cost estimate is the total R and D cost, a figure used mostly for purposes of economic analysis. This figure refers to the unit costs of developing and marketing the BRET stove. BRET technical staff allocated resources to the printing of brochures and posters, to exhibitions, as well as labor time in the promotion of the stoves. In addition, a value of BRET's overhead common operating expenses during the period was also assigned to the stove, reflecting the common support costs that BRET carried as part of its research and development efforts in behalf of the stove.

Table 5 also lists the unit sales prices of the stoves. Since the most recent cost estimates for the stoves exceed the actual sales prices by varying margins, the sale price of the stove is a subsidized one. For purposes of analysis, the actual sale price was neglected in favor of the delivered production cost, since this is a more relevant figure in an actual commercial environment.

D. **Estimation of BRET Stove Benefits**

As noted in the first part of this section, there are many conceptual issues involved in estimating the benefits of the BRET stove. Whether for financial or for economic analysis, the primary benefit that has been used is the value of fuelwood savings. Table 6 summarizes the value of fuelwood savings under a broad variety of assumptions so that one could take into account such conceptual issues as differences in the distribution of household end uses of wood energy as well as differences in the thermal efficiency of open fire systems. In addition, because survey estimates of fuelwood vary widely (as noted in Table II), the value of fuelwood savings has been varied according to the market price of fuelwood. In all cases, however, the quantity of fuelwood savings has been based on estimates of household wood energy use reported in Table 1.

Most tests of the economics of the BRET metal stove have been based on household wood energy savings of ten and twenty percent. For purposes of comparison, the recent ODA study of rural energy use in Botswana concluded that the BRET metal stove would at most provide a wood energy savings of between five and fifteen percent, although the reasons for this conclusion were not spelled out fully in the report. On the other hand, BRET laboratory controlled tests of the BRET stove report fuelwood savings potential of up to fifty percent, and more typical household savings on the order of thirty-five percent. Because the economics of the BRET stove are likely to depend critically on the magnitude of wood energy savings, the ten and twenty percent figures were used to provide a more conservative set of tests.

Figure 6

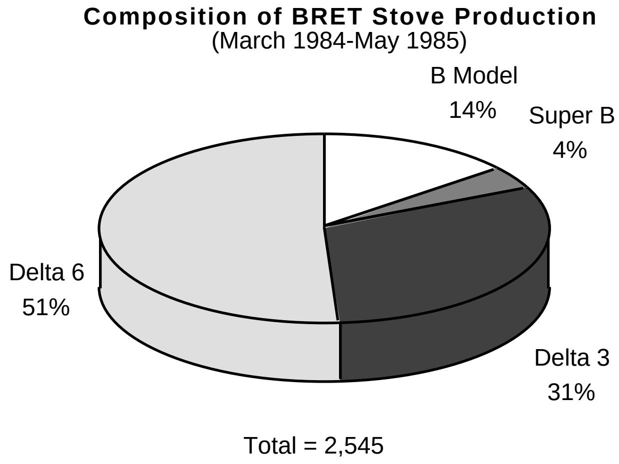

Composition of BRET Stove Production
(March 1984-May 1985)
B Model
14%
Super B
4%
Delta 6
51%
Delta 3
31%
Total = 2,545

Table 3

Comparative Material Cost of the BRET Metal Stoves

(Based on June 1985 Pula Prices)

Material	**"B"**	**"Super B"**	**"Delta 3"**
Grate (1.6mm)	0.80	1.25	1.73
	2.22		
Top ring (l.0mm)	1.70	2.09	none
	none		
Bottom plate(0.8mm)	1.32	1.46	none
	none		
Outside wall	2.35	3.39	3.22
	3.36		
	(0.5 gauge)	(0.8 gauge)	(0.8 gauge)
Door	included	0.15	included
	0.15		
	1.	(0.5 gauge)	(0.8 gauge)
Inside wall(l.0mm)	2.10	2.51	1.45
	1.61		
*Rivets	0.13	0.13	0.26
	0.26		
Grill(expanded metal)	0.68	1.45	0.68
	1.45		
Grill handle(0.5mm)	0.12	0.12	0.12
	0.12		
.35 wire	0.16	0.24	0.16
	0.24		
.60 hoop handle	0.16	0.24	0.16
	0.24		
*Pot supports(3)	none	none	0.75
	0.78		
Total	9.52	11.65	9.13
10.40			
Total (w/o grill)	8.72	10.08	8.33
8.83			

(Costs include wasted material)

Examples of 1985 prices in pula:

Six-meter 1cm reinforcing rod	4.10
Six-meter 6 cm reinforcing rod	1.32
(50kg) wire .35 gals.	39.75
expanded grill metal	26.23
black 1.6 sheet	40.00
0.5 galvanized sheet	19.50
0.8 galvanized sheet	27.00
1.0 galvanized sheet	23.50

Source: Data collected from BRET invoices with whole unit costs partitioned per the 1984 cost comparison in Eric Brunet and John Ashworth, *Technical Adaptation: BRET Wood-Conserving Metal Stoves*. (Burlington, Vt.: ARD, Inc., July, 1984), p. 15.

1. The BRET Stove Production Guide specifies inside wall and top materials at 1.0mm thickness, in contrast to the 1984 Brunet Ashworth listing of 0.8mm.

* Rivet and pot support costs estimated indirectly from materials as no direct invoicing was available.

Table 4

Stove Production Tool Costs

(Gaborone Prices as of June 1985)

	Technical Role			**Annual Cost**			
	Item	Ec. Life in years	Pula Price	"B" Model	Delta Model	"B" Model	Delta Model
I.	**Modular Tools**						
	Ball peen hammer, 500 gr	108.46		R(required)	R	0.85	0.85
	Ball peen hammer, 750 gr	10	11.08	R	R	1.10	1.10
	Cross peen hammer, 350 gr	10	13.15	R	None	1.32	-
	Straight tin strips, 12"	2	16.12	R	R	8.06	8.06
	Aviation type snips	3	23.75	O	0	7.92	7.92
	Cold chisel, 3/4" or l"x8"	5	10.00	R	R	2.00	2.00
	*Hole punch, 0.4 to 0.5mm	8	4.00	R	R	0.50	0.5Q
	*Hole punch, 12mm-14mm	8	5.00	R	R	0.63	0.63
	Hacksaw	5	8.60	None	R	-	1.72
	Hacksaw blades	1	1.02 ea.	None	R	-	1.02
	Scriber	3	n/a	R	R	0.92	0.92
	Smooth flat file	3	2.77	O	O	1.15	1.15
	Bastard file	3	3.45	Recomm.	Recomm.	3.75	3.75
	**0.5mm grooving tool	4	15.00	R	R	5.00	5 00
	**0.8mm half-round tool	4	20.00	Opt.	Opt.	n/a	n/a
	Edgetracing tool	5	n/a	-	-	-	-
	Rivet tool	5	24.00	Opt.	Opt.	4.80	4.80
	Sub-Total			86.61	82.73	36.68	39.42
II.	**Fixed Tools**						
	1 standard rail	15	38.00	R	R	2.53	2.53
	1 hole punching anvil	15	1-10	R	R	0.37	0.37
	1 Grate cutting anvil	15	1-10	R	R	0.37	0.37
	Sub-Total			11.00	11.00	3.27	3.27

III. **Template Production Tools**						
1 straight edge ruler, 6Ocm.	1	7.45	R	R	7.45	7.45
1 square, Mech./Carpenter	1	5.81	R	R	5.81	5.81
1 center punch	3	3.09	R	R	1.03	1.03
1 standard measuring tape	3	6.60	R	R	2.20	2.20
Sub-Total			17.25	17.25	16.49	16.49
IV. **Grand Total**			114.86	110.98	56.44	59.18

Source: Data compiled by BRET staff in Gaboronе.

a. Tool set based on Eric Brunet and John Ashworth, *BRET Metal Stove Production Guide for "B" and "Delta 3" Stoves* (Burlington, Vt.: ARD, Inc., July 1984), p. I-2.

* Approximate figures as units are sold only as sets.

** Approximate, by order only.

n/a = not available. Economic life of tools based on typical usage and depreciation rates. Annual cost is based on the amount of the purchase price that is depreciated in a typical year.

Table 5

BRET Stove Unit Costs

(March 1984 - May 1985)
(in Pula)

	Item:	**B Model**	**Super B**	**Delta 3**	**Delta 6**
1.	Material	9.52	11.65	9.13	10.40
2.	Labor	10.00	10.00	7.87	6.50
3.	Material transport	.68	.68	.00	.00
4.	Warehouse transport	.83	.83	.10	.00
5.	Production tool cost	.13	.13	.14	.04
6.	Training cost	1.56	1.56	1.56	1.56
7.	Basic Production Cost (Financial Analysis Variable)	22.72	24.85	18.80	18.50
8.	Inventory Storage	.50	.50	.70	.70
9.	Distribution transport	.46	.46	.46	.46
10.	Delivered Production Cost (Financial Analysis Variable)	23.68	25.81	19.96	19.66
11.	Promotion material cost	.73	.73	.73	.73
12.	Promotion labor cost	7.70	7.70	7.70	7.70
13.	Exhibition cost	.34	.34	.34	.34
14.	BRET staff overhead cost	8.90	8.90	8.90	8.90
15.	Development Cost		17.67	17.67	17.67
16.	Total R & D Unit Cost (10 + 15) (Economic Analysis Variable)	41.35	43.48	37.63	37.33
17.	**Unit Sale Price**	**15.00**	**17.00**	**15.00**	**17.00**
18.	**Per Unit Subsidy as fraction of**:				
	a. Basic Production Cost	33.97	31.59	20.21	8.10
	b. Delivered Production Cost	36.65	34.13	24.85	13.53
	c. Total Unit Development Cost		63.72	60.90	60.13

Source: BRET staff data. Estimates for the B and Super B model based on artisan production at Molepolole. Delta 3 estimates based on PFP program in Gaborone. Delta 6 estimates based on data from RK Electrical and Botswana Steel in Gaborone.

E. **Sensitivity Analysis of BRET Stoves**

Tables 7 through 10 provide a summary of the sensitivity tests used in the assessment of the BRET stoves. In Table 7, a base case of twenty percent fuelwood savings was used, along with a projected increase of five percent per year in the real price of fuelwood.[1] In addition, there were several additional assumptions used in the analysis that bear some discussion. One is the economic lifetime of the stove. The basic assumption used here was that the stove would last for five years, but that over the lifetime of the stove, there would be a replacement of the grate in years two and four, a replacement of the liner in year three, and a replacement of the door in year four. As to benefits, a price of three thebe per kilograms of wood was used.

In purely financial terms, with a twenty percent fuelwood savings and a three thebe per kilograms of fuelwood price, all of the BRET stove models are economic. Moreover, if one uses the expanded R and D total unit cost figure to conduct an economic analysis, all of the models are still economic, even at discount rates of up to twenty percent. Given these results, a second set of tests was then conducted using shadow prices to account for market price distortions. Results for the economic analysis of the stove under the basic assumptions used in Table 7 are reported in Table 8. Here, the principal adjustments were in adjusting the foreign exchange component of materials and tools to more accurately reflect the potential of an overvaluation of the Pula. Since the stoves were quite economic using the delivered unit cost estimates in the financial analysis, Table 8 reports results only for tests based on the total and D unit cost. Again, even allowing for foreign exchange overvaluation, with a twenty percent fuelwood savings, a three thebe per kilograms of fuelwood price, and a five percent per year increase in the real price of fuelwood, all of the BRET stoves are economic.

To provide a more stringent assessment of the economics of the BRET stove, three additional sets of financial tests were conducted. All of these are reported in Table 9. The first was based on a fuelwood savings of twenty percent and a fuelwood price of three thebe per kilograms, but in which no increase in the real price of fuelwood would take place. Again, all of the stoves proved economic even for discount rates of up to twenty percent. The second set of tests was based on a zero rate of increase in the real price of fuelwood, a fuelwood price of three thebe per kilograms, but only a ten percent level of fuelwood savings. In this case, the B and Super B models are no longer economic, while the Delta 3 and Delta 6 models are only marginally economic in that their internal rates of return are below the government's own discount rate of six percent.

The final set of financial tests was based on a zero rate of increase in the real price of fuelwood, a ten percent rate of fuelwood savings, but in which the value of fuelwood is at four thebe per kilograms. In this case, all of the stoves again become financially profitable, even for discount rates of up to twenty percent. Table X provides a sample output profile for the Delta 6 model used in this latter set of tests. It should also be noted that if the market price of fuelwood is only three thebe, then any higher value of fuelwood would reflect the external benefit of conservation, in which case the evaluation shifts from being purely financial to an economic assessment.

Before drawing any conclusions regarding the economics of the BRET stove, some account should also be taken of potential sources of bias. Let us first take up the question of stove costs. One source of bias is that because of the somewhat limited experience with the BRET stove, we do not know exactly what its lifetime would be in a typical household environment, nor do we know what the frequency of replacement parts would be. As indicated in Table X, tests have been based on a five year lifetime of the stove frame, with intervening replacement of parts. As more experience with the BRET stove is acquired, whether these estimates create a bias in favor of or against the stove will become clearer.

Another potential source of bias in BRET stoves is the estimates for unit production costs. As already noted, the estimates used in this analysis have been based on BRET production experience. Because BRET's mission has been to develop marketable prototypes, it is quite possible that in an actual production environment, stove unit costs could be lowered as production experience is acquired. If so, then the BRET stove basic and delivered production unit costs used in the financial analysis are overestimated.

Although some economic analysis tests were performed using shadow foreign exchange rates, the extent of bias in BRET stove costs can not be determined directly. Here the problem is that imported materials and tools may cost more to Botswana in real resource terms if the Pula is overvalued. However, even allowing for the foreign exchange component of the stove, the extent of this potential source of bias does not appear to be as substantial as in the case of some investment projects.

Turning to the benefits side, one potential source of bias is in terms of interfuel substitution. As already noted in the introduction to the discussion of the BRET stove, because stoves do represent a real outlay to the average potential consumer, there is some uncertainty as to how consumers would respond to rising real prices of fuelwood. They may first of all increase the thermal efficiency of open fire systems. On the other hand, they may also shift to another source of energy, most likely paraffin or natural gas. Moreover, even if they do purchase a BRET stove, their consumption of light energy may expand as the light provided by the open fire system is reduced. Since there is little evidence from the various surveys that have been conducted of energy use that could shed light on these issues, the general operating assumption in the present analysis has been that no significant interfuel substitution would occur. This assumption has been used in both the financial and economic analyses.

Beyond the problem of interfuel substitution, another source of potential bias is in terms of the valuation of time saved cooking as well as the valuation of time saved in gathering fuelwood. Since the benefits stream uses a market price of fuelwood, at least some of the potential bias from omission of time saved in gathering fuelwood has been taken into account. Yet because of measurement difficulties, no account of the value of time saved in cooking has been included in the analysis. Stove benefits may thus be underestimated as they apply to both the financial and economic analyses.

Table 6

Value of Base Year Annual Savings from BRET Metal Stove

(1985 Base Year Reference Case)

For 1985, Botswana's national fuelwood consumption is expected to be at 174,160 tonnes of oil equivalent. At .35 physical tonnes of fuelwood per tonne of oil equivalent, this is equivalent to 497,600 tonnes of fuelwood, which when divided by the projected 1985 population yields a per capita annual level of fuelwood consumption of .4539 tonnes, or 1.24 kg. per day. With an estimated household size of 5.81 persons, this translates into a daily household consumption of fuelwood of 7.2251 kg, which on an annual basis yields 2637.17 kg.of fuelwood. In the table below, alternative possible levels and values of fuelwood savings obtainable by a household's purchase of a BRET stove are given for purposes of economic evaluation. In all cases, the reference is in terms of the quantity and value of savings in terms of the no-stove case of 2637.17 kg of fuelwood per household per year.

1. Percentage of Base Case Fuel wood saved:	5%	10%	15%	20%	30%	40%	50%
2. Quantity of Fuelwood saved(4.):	132	264	396	527	791	1055	1319
3. Annual Pula Value of Fuelwood Saved with Kg price at:							
a. 3 thebe	6.6	7.9	11.9	15.8	23.7	31.7	39.6
b. 4 thebe	5.3	10.6	15.8	21.1	31.6	42.2	52.8
c. 5 thebe	6.6	13.2	19.8	26.4	39.6	52.8	66.0
d. 10 thebe	13.2	26.4	39.6	52.7	79.1	105.5	131.9

Sources: The range of price estimates has been based on sample fuelwood prices reported in recent energy surveys conducted throughout Botswana (Oki 1984, Gay 1985, ODA 1985). The range of fuelwood savings potential of the BRET stove has been based on various laboratory and field tests conducted by BRET staff. Two BRET reports that have been used in these estimates are: Howard S. Geller, Bai Leteemane, Theresa M. Powers, and James Sentle, *Prototype Metal and Mud Wood-Burninq Cook Stoves for Botswana.* (Burlington, Vt.: ARD, Inc., under U.S.AID contract 633-0209-C-OO- 1024-00, May, 1983), pp. 24, and c-l to c-4. Using the PHU(percent heat utilized) index, the potential savings from prototype models range from 25 to 50 percent. The other report is by Carmen Penty, *Earthen Stove Consultancy for the Botswana Renewable Energy Project.* (Burlington, Vt.: ARD, Inc.,under U.S.AID contract 633-0209-C-00-1024-00), p. 7, 49, p. 50. In addition, account has also been taken of the recent ODA report, *A Study of Energy Utilization and Requirements in the Rural Sector of Botswana* (London: ERL Energy Resources, Ltd. for Overseas Development Administration, May 1985), pp. 35-36, in which comparative tests of open fire and BRET stoves led the authors to conclude that expected fuelwood savings from the BRET stove would be on the order of 5 to 15 percent.

Other sources of bias in the estimation of stove benefits include the value of household safety, portability, and environmental protection. Stoves do enhance household safety by reducing the risk of uncontrolled fire as well as in providing protection to young children who might otherwise be burned. Because stoves are portable, they more readily fulfill the shifting seasonal pattern of indoor and outdoor cooking done by traditional Batswana, as well as shifts in cooking demand between village settlements and cattle posts. Because of estimation difficulties, no allowance was made for these financial benefits. Finally, because stoves reduce fuelwood consumption, they increase the degree of environmental protection, which constitutes an economic benefit to society. As already noted, increased environmental protection provides many diffuse benefits that are difficult to measure, even though they may be important to society. In any case, because none of these benefits have been included in the analysis, the magnitude of benefits from use of the BRET stove may be underestimated.

Taken together, the BRET stove appears to be economic under a wide variety of technical and economic assumptions. Because the internal rate of return of the stove in most cases exceeds the government's own six percent rate of discount, the stoves would appear to qualify for some form of continuing government assistance such as under the Financial Assistance Policy. Accordingly, the government should give serious consideration to further marketing and dissemination efforts of the stove, with a view toward self-sustaining commercialization in the years ahead.

Table 7

Sensitivity Analysis of BRET Stoves

	Delivered Cost Basis			**Total R&D Unit Cost**		
	(financial analysis)			(economic analysis)		
Model and Parameters:	**NPV**	**IRR**	**B/C**	**NPV**	**IRR**	**B/C**
		(Pula)			(Pula)	
A. **Discount rate**						
1. **"B" Model**:						
a. 6 percent	37.5	151.9	1.93	19.8	34.4	1.34
b. 10 percent	33.4	151.9	1.86	15.7	34.4	1.27
c. 20 percent	25.4	151.9	1.70	7.7	34.4	1.14
d. 30 percent	n/a	151.9	n/a	2.0	34.4	1.03
2. **"Super B" Model:**						
a. 6 percent	33.9	112.8	1.77	16.2	27.8	1.26
b. 10 percent	29.9	112.8	1.70	12.2	27.8	1.20
c. 20 percent	22.2	112.8	1.56	4.5	27.8	1.07
d. 30 percent	n/a	112.8	n/a	-1.1	27.8	0.98
3. **"Delta 3" Model**:						
a. 6 percent	44.1	336.8	2.31	26.1	48.5	1.50
b.10 percent	39.8	336.8	2.23	21.8	48.5	1.43
c.20 percent	31.4	336.8	2.04	13.4	48.5	1.27
d.30 percent	n/a	336.8	n/a	7.4	48.5	1.15
4. **"Delta 6" Model**:						
a. 6 percent	44.3	338.3	2.33	26.6	49.8	1.52
b.10 percent	40.0	338.3	2.24	22.3	49.8	1.44
c.20 percent	31.5	338.3	2.05	13.9	49.8	1.29
d.30 percent	n/a	338.3	n/a	7.8	49.8	1.17

B. **Common technical and economic parameters used for all four models and for the range of discount rates listed**:

1. **Technical**:
    - a. Fuelwood Savings
    - b. 527 Kg per year (20 percent)
    - c. Stove durability:
        - i. 5 year life
        - ii. Replace grate in years 2 and 4
        - iii. Replace liner in year 3

iv. Replace door in year 4

2. **Financial/economic**:
   a. Fuelwood price at 3 thebe/kg.
   b. Rate of fuelwood price increase at 5 percent per year in real terms

c. **Stove unit prices:**	**Delivered Cost Basis**	**Total Unit Cost Basis**
i. B model	23.68 Pula	41.35 Pula
ii. Super B model	25.81 Pula	43.48 Pula
iii. Delta 3	19.96 Pula	37.63 Pula
iv. Delta 6	19.66 Pula	37.33 Pula

Source: Tabular data from BRET staff sources included in this report.

One remaining issue surrounding the economics of the BRET stove is in what kind of market is it most likely to succeed. Because it makes sense mostly in those areas where the price of fuelwood is at least three thebe per kilograms, and because its current production costs are in the neighborhood of twenty Pula, the most likely market is in urban areas. Table 11 provides a profile of all communities in Botswana that as of the 1981 census had populations of at least 4,500 persons. Although Batswana authorities traditionally specify only the largest six communities of Table 11 as "urban", the market potential of the stove extends down as far as communities as small as 4,500 as they tend to be located in wood-scarce areas of the country and because they are more likely to be more wholly integrated into the cash economy.

Table 8

Sensitivity Analysis of BRET Stoves

Economic Analysis Cost	**Delivered Cost Basis**			**Total R&D Unit**		
Model and Parameters:	NFV (Pula)	IRR (Pula)	B/C	NPV	IRR	B/C
A. **Discount rate**						
1. **"B" Model**:						
a. 6 percent						
i. SFX = 1.1	n/a	n/a	n/a	17.9	30.7	1.30
ii. SFX = 1.2	n/a	n/a	n/a	13.4	22.9	1.20
b. 10 percent						
i. SFX = 1.2	n/a	n/a	n/a	9.4	22.9	1.15
2. **"Super B" Model**:						
a. 6 percent						
i. SFX = 1.1	n/a	n/a	n/a	14.4	24.7	1.22
ii. SFX = 1.2	n/a	n/a	n/a	9.5	17.3	1.14
b. 10 percent						
i. SFX = 1.2	n/a	n/a	n/a	5.7	17.3	1.08
3. **"Delta 3" Model:**						
a. 6 percent						
i. SFX = 1.1	n/a	n/a	n/a	24.7	44.5	1.46
ii. SFX = 1.2	n/a	n/a	n/a	20.4	34.8	1.35
b. 10 percent						
i. SFX = 1.1	n/a	n/a	n/a	16.2	34.8	1.29
4. **"Delta 6" Model**						
a. 6 percent						
i. SFX = 1.1	n/a	n/a	n/a	25.2	45.8	1.48
ii. SFX = 1.2	n/a	n/a	n/a	20.9	35.9	1.37
b. 10 percent						
i. SFX = 1.2	n/a	n/a	n/a	16.7	35.9	1.30

B. **Common technical and economic parameters used for all four models and for the range of discount rates listed**:

1. **Technical**:
    - a. Fuelwood Savings
    - b. 527 kg per year (20 percent)
    - c. Stove durability:
        - i. 5 year life
        - ii. Replace grate in years 2 and 4
        - iii. Replace liner in year 3
        - iv. Replace door in year 4
2. **Financial**:
    - a. Fuelwood price at 3 thebe/kg
    - b. Rate of fuelwood price increase at 5 percent per year in real terms
    - c. Stove unit prices:

c. Stove unit prices:	Delivered Cost Basis	Total Unit Cost Basis
i. B model	n/a	42.70 Pula
ii. Super B model	n/a	44.78 Pula
iii. Delta 3	n/a	38.76 Pula
iv. Delta 6	n/a	38.45 Pula

With this broader definition of urbanisation, projections of the growth of the potential market for wood stoves have been made. Using estimates of the percentage of households that depend primarily on wood energy but who do not have wood stoves, the estimated number of households that are potential buyers of wood stoves as of 1985 is 60,000. Using demographic projections made by census officials in Botswana and allowing for varying degree of interfuel substitution, the wood stove market is expected to grow by approximately twenty percent per year between 1985 and 1991. Thus, the potential market for the BRET metal stove is substantial.

Table 9
Sensitivity Analysis of BRET Stoves II

(based on zero real price increase in fuelwood)

	Sensitivity Parameters: (based on BRET Delivered Cost Prices)		
	NPV	**IRR**	**B/C**
Financial Analysis:			
I. **Basic Assumptions**:			
A. Fuelwood price at 3 thebe/kg			
B. 527 kg.wood savings(=20%)			
C. Results for BRET stoves:			
1. **B Model**			
a. Delivered Cost Price: P23.68			
b. Results for Discount Rates of:			
i. 6 percent	30.53	134.78%	1.76
ii. 10 percent	27.14	134.78%	1.70
iii. 20 percent	20.54	134.78%	1.56
2. **Super B Model**			
a. Delivered Cost Price: P25.81			
b. Results for Discount Rates of:			
i. 6 percent	28.40	102.66	1.67
ii. 10 percent	25.01	102.66	1.61
iii. 20 percent	18.41	102.66	1.48
3. **Delta 3 Model**			
a. Delivered Cost Price: P19.96			
b. Results for Discount Rates of:			
i. 6 percent	34.25	268.05	1.94
ii. 10 percent	30.86	268.05	1.88
iii. 20 percent	24.26	268.05	1.74
4. **Delta 6 Model**			
a. Delivered Cost Price: P19.66			
b. Results for Discount Rate of:			
i. 6 percent	34.55	289.97	1.96
ii. 10 percent	31.16	289.97	1.89
iii. 20 percent	24.26	289.97	1.76

	(based on BRET Delivered Cost Prices:)		
	NPV	**IRR**	**B/C**
Financial Analysis:			
II. **Basic Assumptions**:			
A. Fuelwood price at 3 thebe/kg			
B. 264 kg.wood savings(=10%.)			
C. Results for BRET stoves:			
1. **B Model**:			
a. Delivered Cost Price: P23.68			
b. Results for Discount Rates of:			
i. 6 percent	-4.74	-6.41	0.88
ii. 10 percent	-5.79	-6.41	0.85
iii. 20 percent	-7.80	-6.41	0.78
2. **Super B Model**:			
a. Delivered Cost Price: P25.81			
b. Results for Discount Rates of			
i. 6 percent	-6.87	-10.24	0.83
ii. 10 percent	-7.92	-10.24	0.80
iii. 20 percent	-9.93	-10.24	0.74
3. **Delta 3 Model**			
a. Delivered Cost Price: P19.96			
b. Results for Discount Rates of:			
i. 6 percent	-1.02	2.68	0.97
ii. 10 percent	-2.07	2.68	0.94
iii. 20 percent	-4.08	2.68	0.87
4. **Delta 6 Model**			
a. Delivered Cost Price: P19.66			
b. Results for Discount: Rates of:			
i. 6 percent	-0.72	3.61	0.98
ii. 10 percent	-1.77	3.61	0.94
iii. 20 percent	-3.78	3.61	0.88

Sensitivity Parameters:

	(based on BRET Delivered Cost Prices)		
	NPV	**IRR**	**B/C**
Financial Analysis:			
III. **Basic Assumptions**:			
A. Fuelwood price at 4 thebe/ kg			
B. 264 kg.wood saved(=10%)			
C. Results for BRET Stoves:			
1. **B Model**			
a. Delivered Cost Price: P23.68			
b. Results for Discount Rates of:			
i. 6 percent	7.31	27.08%	1.18
ii. 10 percent	5.46	27.08%	1.14
iii. 20 percent	1.88	27.08%	1.05
2. **Super B Model**			
a. Delivered Cost Price: P25.81			
b. Results for Discount Rates of:			
i. 6 percent	5.81	19.18%	1.12
ii. 10 percent	3.33	19.18%	1.08
iii. 20 percent	-0.24	19.18%	0.99
3. **Delta 3 Model**			
a. Delivered Cost Price: P19.96			
b. Results for Discount Rates of:			
i. 6 percent	11.03	48.19%	1.30
ii. 10 percent	9.18	48.19%	1.26
iii. 20 percent	5.60	48.19%	1.17
4. **Delta 6 Model**			
a. Delivered Cost Price: Pl9.66			
b.Results for Discount Rates of:			
i. 6 percent	11.33	50.57%	1.31
ii. 10 percent	9.47	50.57%	1.27
iii. 20 percent	5.90	50.57%	1.18

Table 10

BRET Stove Financial Analysis

	Period:	1.00	2.00	3.00	4.00	5.00
A. **Model: Delta 6**	Assumptions:					
1. **Technical parameters**:						
a. Annual fuelwood saving	10%					
a. fuelwood saved	264 kg.					
b. Stove life	5 years					
c. Replace grate in year	2 and 4					
d. Replace liner in year	3.00					
e. Replace door in year	4.00					
f. HH kg/P.						
2. **Economic parameters**						
a. Discount rate	.06					
b. Shadow wage rate	1.00					
c. Shadow For.Exch. rate	1.00					
d. Stove Selling Price	19.66					
e.Ann.Rate Wood Price Increase	0%					
f. Price per kg of firewood	4 thebe					
B. **Costs**:	Pula:					
1. BRET Stove Purchase Price	19.66	19.66				
2. Replacement grate			4.00, 5.00		4.00	5.00
3. Replacement liner	6.00		6.00			
4. Replacement door		3.60			3.60	
2. **Annual Cost** Flow		19.66	4.00	6.00	8.60	.00
3. **Discounted Annual Costs**		19.66	3.77	5.34	7.22	.00
4. **Present Value of Costs**	**35.99**	Pula				
C. **Benefits:**		Pula:				
1. Value of fuelwood saved	10.60	10.60	10.60	10.60	10.60	10.60
2. Value of cooking time saved	.00	00	00	00	00	00
3**. Annual Benefit Flow**		**10.60**	**10.60**	**10.60**	**10.60**	**10.60**
4. **Discounted Annual Benefits**		10.60	10.00	9.43	8.90	8.40
5. **Present Value of Benefits**	**47.33**	Pula				
D. **Financial Evaluation**:						
1. **Net Present Value**		11.34	Pula			
2. **Internal Rate of Return**		50.57	Pct.			
3. **Benefit-Cost Ratio**		1.31				

Notes:

a. Stove price based on delivered production cost

b. At 2.5 hours per day of wood collection per HH, 10% wood savings = I/6 of one day per week, or 1.31 weeks of 10 hour days.

Table 11

Urbanisation in Botswana: Communities With at Least 4500 Population

(Based on 1981 Census Data)

Community	**Population** (1981)	**Number of Households**	**Wealth Index** (1981)	**Pct.Using Wood As Primary Fuel**	**Kg.Wood Consump Per.Cap. Per Day**
Ngwaketse					
Kanye	20,215	3,625	4189.5%	n/a	n/a
Moshupa	6,612	1,177	3895.9	n/a	n/a
Southeast					
Ramotswa	13,009	2,085	4991.5	n/a	n/a
Tlokweng	6,653	1,111	5678.8	n/a	n/a
Kweneng					
Molepolole	20,565	3,676	6170.0	1.00	10.4
Thamaga	6,520	1,150	3395.2	n/a	n/a
Kgateng					
Mochudi	18,386	3,453	4692.3	n/a	n/a
Central Serowe					
Serowe	23,661	3,669	3675.0	1.47	26.7
Palapye	9,593	1,614	3685.9	1.65	32.8
Central Mahalapye					
Mahalapye	20,172	3,247	4189.9	1.33	n/a
Shoshong	4,600	733	2797.8	0.64?	?
Central Bobonong					
Mmadinare	5,234	884	2997.7	n/a	n/a
Bobonong	4,711	930	2295.l	1.19	n/a
Central Boteti					
Letlhakane	5,169	737	1888.0	n/a	n/a
Central Tutume					
Tonota	6,566	1,020	4296.9	n/a	n/a
Ngamiland					
Maun	14,925	2,336	2390.6	n/a	n/a
Etsha	4,711	1,100	6	97.6	n/a
Gaborone	59,657	10,716	7424.0	1.12	14.1
Francistown	31,065	6,031	4778.2	n/a	n/a
Lobatse	19,034	3,029	7534.4	1.63	13.7
Selebi-Phikwe	29,469	5,399	5664.8	1.81	22.8
Orapa	5,229	6,117	820.0	0.0	n/a
Jwaneng	5,567	418	792.9	n/a	n/a
Total	**341,323**	**58,757**			
Sample HH Size:		5.81 persons			
National HH Size:		5.95 persons			

Source: Government of Botswana, 1981 Census.Data for extent of stove ownership based on John Gay, *Urban Energy Survey*, in Serowe, Palapye, Molepolole, Selibe-Phikwe, Lobatse, and Gaborone.(Burlington, Vt.ARD, Inc., for U.S.AID, contract no. 633-020-c-00-1024-00, January 1985), p. 45. Wealth index based on ODA methodology used in Energy Planning Associates, *A Study of Energy Utilization and Requirements in the Rural Sector of Botswana*, vols. I and II.(London: Energy Resources Ltd., prepared for Overseas Development Administration, May 1985), pp. 41-42.

IV. **BRET Retained Heat Cookers**

A. Conceptual Issues in the Analysis of BRET Retained Heat Cookers

A retained heat cooker is a relatively inexpensive household technology that permits one to conserve on the consumption of cooking energy resources. Conservation of cooking energy is achieved by first cooking a quantity of food over a conventional source of heat energy for a brief period of time, then transferring the pot of semi-cooked food into a sealed container where the retained heat permits the food to continue cooking over a longer period of time. Because retained heat cookers are used so little in other countries and because so few of them have been produced or sold thus far in Botswana, there are several conceptual issues regarding the assessment of this technology that should be discussed at the outset.

Although cooking with a retained heat cooker does conserve conventional cooking energy, because food takes a longer time to cook, whether the retained heat cooker may be viewed as beneficial to a typical household is somewhat problematic. The difficulty here is that while the retained heat cooker enables one to save some cooking time with a traditional technology, e.g., an open fire, the longer cooking time associated with use of the retained heat cooker may also pose a constraint on household time. If one considers the responsibility of extra cooking time with the retained heat cooker as a cost in terms of what else one could be doing with that time, then the benefits of fuel saving are not as great as they would be if one valued the extra cooking time at a zero cost, or as a benefit. Conversely, to value the extra cooking time with the retained heat cooker as a benefit is also difficult in that one is making an explicit comparison of the disutility of the extra cooking time with a conventional cooking technology with the extra cooking time using a retained heat cooker.

To illustrate the difficulty in measuring the benefits of the retained heat cooker, consider the energy-time trade-offs listed in Table 13. As one indication, over half of the potential meals that would be cooked with a retained heat cooker consist of porridge. Porridge is most often consumed in the morning. In order to take full advantage of the benefits of the retained heat cooker in this case, one would have to get up earlier in the morning, or else allow the porridge to cook in the retained heat cooker throughout the night. As there is thus far only limited data on how households might take advantage of the fuelwood energy savings available through use of the retained heat cooker, it is problematic whether potential Batswana consumers would be willing to make such adjustments just in order to take advantage of the benefits of the retained heat cooker. For all of these reasons, the analysis of the BRET retained heat cooker is based on varying assumptions regarding the value, or opportunity cost, of extra cooking time. As will be seen, it turns out that this becomes a crucial consideration in deciding whether the retained heat cooker is economic or not.

Another issue that arises in the assessment of BRET retained heat cookers is how frequently they would be used, as well as what is the magnitude of residential energy savings possible from their use. As in the case of BRET stoves, there are insufficient data to estimate directly the proportion of residential energy consumption that is devoted to specific end uses, which in this case is cooking energy. Consequently, the estimation of energy conservation possible from the retained heat noter has been based on a range of possible values.

It should also be noted that the benefits of the retained heat cooker are complicated by the extent of energy conservation that a household may make with a conventional energy system in response to rising real prices of conventional energy resources. Again, the assumption used in this analysis is that households would respond to some level of real prices of conventional energy by shifting to a residential energy conservation technology rather than attempting to increase the thermal efficiency of a conventional energy system. Although there is also the possibility that households could also shift to alternative sources of energy, this does not play a significant role in the assessment of retained heat cookers since a retained heat cooker can conserve cooking energy regardless of the conventional energy resource that is used.

B. **Estimation of BRET Retained Heat Cooker Unit Costs**

Estimation of BRET retained heat cooker production unit costs have been based on workshop data developed over the past 15 months. BRET staff have estimated that during this period, workshop participants produced a total of 157 units. However, because workshop participants were given the retained heat cookers that they had been trained to produce upon completion of the workshops, it has not been possible to make a more direct estimate of production unit costs. What has been done is a reconstruction of the respective cost components from the various workshops.

Table 12 summarizes the production unit cost estimates of the BRET retained heat cooker. As was done in the case of BRET stoves, a basic production cost, a delivered production cost, and a total R and D Unit Cost have been estimated. Since these estimates do not reflect any attempt to produce retained heat cookers on a commercial production basis, the only other cost comparison that has been available is an imported commercial model produced in Soweto, South Africa. Given the limited data, the Pl6.00 delivered price of the South African commercial model as well as the P11.78 BRET delivered production cost price comprise the two basic unit cost estimates used in the financial analysis.

One other issue involving the retained heat cooker has been the estimation of recurrent life cycle costs. As in the case of BRET stoves, with limited user experience, it has not been possible to estimate directly the level and frequency of replacement and maintenance costs. The assumptions used in the analysis have been that the retained heat cooker will last for only three years, and that the box frame, the cloth liner, and top will be replaced in year two, leaving only the basic insulation material having the full three-year lifetime. Although the imported South African commercial model and some BRET prototypes presently use polystyrene beads whose useful life could well exceed three years, because local models have been based with a view toward maximum use of local rather than imported materials, the three-year expected life of the insulation material has been used as a medium case assumption.

C. **Estimation of BRET Retained Heat Cooker Benefits**

As pointed out in section A, because retained heat cookers save energy by taking a longer time to cook food, the measurement of benefits is somewhat problematic. In order to arrive at an estimate of retained heat cooker benefits, two types of calculations were performed. The first was the derivation of retained heat cooker performance data, summarized here in Table 13. What table 13 shows is a comparison of the energy-time relationships associated with the use of a retained heat cooker in comparison with a conventional energy technology, be that an open fire wood energy system, a wood stove energy system, a paraffin energy cooking system, or a gas cooking energy system Based on tests performed by BRET staff, as well as on the frequency distribution of types of food cooked by Batswana households, an estimate of the annual cooking energy savings possible from use of the retained heat cooker has been estimated. In the case of the four categories of food that are most likely to be cooked with a retained heat cooker, if one were to use the retained heat cooker for cooking one hundred percent of these meals the potential annual wood energy equivalent savings would be just under four hundred kg, which represents approximately fifteen percent of household annual energy consumption. What this wood energy equivalent savings also represents is 644.3 extra cooking hours per year, which is equivalent to 64.43 ten-hour days.

The second step in the estimation of benefits from the retained heat cooker is to take various possible usage rates and derive the corespondent value of wood energy equivalent savings based on alternative values of the wood energy. These estimates are reported in Table 14 and for fuelwood equivalent savings of between just under forty kg and just under four hundred kg, the value of potential fuelwood energy annual savings for prices of between 3 and 5 thebe per kg range from P1.19 to P19.87. These values have been used as the principal benefit stream in the financial analysis.

D. **Sensitivity Analysis of Retained Heat Cookers**

Given the three-year estimated lifetime of a retained heat cooker, the economics of this technology depend less on differences in the rate of discount used than they do on the estimation of specific costs and benefits. For this reason a broad range of tests incorporating differing values of costs and benefits has been included in the analysis the results of which are reported in Tables 15 and 17 along with a sample output test in Table 17.

Table 12

BRET Retained Heat Cooker Production Unit Costs

Item:	**Amount** in Pula
1. Fabric material	4.01
2. Needles 4 threads	.10
3. Sewing Machine1	.05
4. Machine repair	.19
5. Insulation	2.93
6. Machine needles	.10
7. Labor2.00	
8. BRET staff training cost	1.15
9. **Basic Production Cost** (Financial Analysis Variable)	**11.53**
10. Inventory storage	.00
11. Distribution transport	.25
12. **Delivered Production Cost** (Financial Analysis Variable)	**11.78**
13. Promotion equipment cost	
a. gasXparaffin stoves	.74
b. manufactured sample RHC's	5.41
14. Promotion material	
a fuelwood for testing	.16
b.paraffin for testing	.06
15. Promotion labor cost	2.29
16. Exhibition cost	2.82
17. BRET staff overhead cost	7.21
18. **Development Cost**	**18.69**
19. Total R and D Unit Cost (12 + 18) (Economic Analysis Variable)	**30.47**
20. **Unit Sale Price**(S.A.Model)	**16.00**

Source: BRET staff data. Estimates for the BRET production model based on 157 units constructed jointly by BRET staff and seminar participants. No effort has been made thus far to sell the BRET RHC model, although a commercial unit made in Soweto, South Africa, is being sold in Botswana for P16.00. For purposes of comparison, Batswana unit labor costs have been estimated at P2.00 per unit.

Table 13

Retained Heat Cooker Performance Data

(Based on Household Food and Cooking Technology Patterns)

	Frequently Consumed Foods: Energy Used	**Seasonally adjusted Per Week: Time Per Meal** (Hours: min.)	**Seasonally adjusted Per Year: Per Meal:** (in Kg.wood eq.)	
A: **Without RHC**:				
Porridge	8.12	422.38	0.43	28 minutes
Meat/Vegetables	2.95	153.42	1.14	59 minutes
Samp/Beans	1.56	81.22	1.54	2 hr.27 min.
Rice	1.50	78.13	1.09	28 minutes
Averages:				
Meals per day:		2.01		
Energy per meal(Kg.Wood eq.)				1.06 kg.
B. **With RHC**:				
Porridge	8.12	422.38	0.43	45 minutes
Meat/Vegetables	2.95	153.42	0.62	2 hr. 15 min.
Samp/Beans	1.56	81.22	0.79	6 hr.14 min.
Rice	1.50	78.13	0.50	45 minutes
Averages:				
Meals per day:		2.01		
Energy per meal(kg.Wood eq.)				0.52
Energy Increase in SavedCooking Time:				
C. **Energy-Time Differences**:				(kg.Wd.eq.)
Porridge		0.50		7 minutes
Meat/Vegetables		0.52		1 hr.16 min.
Samp/Beans		0.75		3 hr.47 min.
Rice		0.59		17 minutes
Averages:				
Annual Energy Savings		Porridge:		210.56 kg.
Potential Per Household		Meat/Veg.:		79.78 kg.
From Use of RHC:		Samp/Beans:		60.92 kg.
(in Kg.Wood eq.)		Rice:		46.10 kg.
Technology/Frequency				
Weighted Household Average of All Foods:				**397.36 kg.** wood equivalent
Approximate Percentage saving of wood equivalent				

energy used in cooking:		25.0 percent
Increase in Annual Cooking Time Per Household From Use of RHC:	Porridge:	120.6 hours
	Meat Veg.:	194.3 hours
	Samp/Beans:	307.3 hours
	Rice:	22.1 hours
Technology/Frequency Weighted Household Annual Average of extra time to cook with RHC:		644.3 hours (or 64.43 ten-hour days)
Ratio of Kg of wood energy saved per extra hour of cooking time with RHC:		.6167 kg. per hour.
1985 estimated national household annual consumption of all forms of energy in kg of wood energy equivalent:		2,640 - 2,720 kg.
Percentage reduction in aggregate energy use obtainable from universal adoption of retained heat cookers:		13 to 14 percent.

Source: BRET staff data on household cooking patterns and energy time tests using open-fire, BRET stoves, Gas stoves, and Paraffin stoves with and without use of retained heat cookers.

In Table 15, a financial analysis based on a one hundred percent upper limit use rate of the retained heat cooker has been done for differing values of the following variables: the price of fuelwood energy savings, different production unit cost models differing assumptions regarding the rate of increase in the real price of fuelwood cooking energy, and differences in the value that one attaches to the opportunity cost of extra cooking time. What these tests show is that as long as one uses the retained heat cooker for one hundred percent of household basic meals, the crucial variables turn out to be the per kg price of fuelwood energy savings as well as the opportunity cost of extra cooking time. If the rate of increase in the real price of energy is zero as long as fuelwood energy savings are valued at least at a price of 3 thebe per kg with a corresponding opportunity cost of extra cooking time valued at less than I thebe per hour, then the retained heat cooker is economic to households. If one allows for a five percent annual rate of increase in the real price of fuelwood energy, then even if the opportunity cost of extra cooking time rises to I thebe per hour, for wood energy prices of at least 4 thebe per kg the retained heat cooker is still economic. What makes this so problematic is that there is no readily discernible basis with which to assign a zero or positive opportunity cost for extra cooking time.

Even if one did not have to contend with the opportunity cost of extra cooking time an equally difficult issue surrounding the assessment of retained heat cookers is whether they would be used for up to one hundred percent of household cooking time. In Table 16, a second set of financial analysis_sensitivity tests has been conducted, this time with no value attached to the opportunity cost of extra cooking time, but with allowance for varying rates of utilization of the retained heat cooker. In these tests, the economics of the retained heat cooker turn critically on whether the technology is used at least fifty percent of the time for fuelwood prices ranging from 3 to 5 thebe per kg, even when one has allowed for a five percent annual rate of increase in the real price of fuelwood. Taken together, what the tests in Table 15 and 16 indicate is that in order for the retained heat cooker to be economic, fuelwood must be valued at least at 3 thebe per kg, the technology must be used at least fifty percent of the time, and that there must be a relatively insignificant value attached to the opportunity cost of extra cooking time.

Since the retained heat cooker is quite sensitive to a few key assumptions, some attention should be given to potential sources of bias in the analysis. On the cost side, mention has already been made of the difficulty in measuring the life cycle costs of the retained heat cooker. Although relatively liberal assumptions regarding replacement rates have been used, because data on the frequency of use are not yet available, the lifetime of the retained heat cooker could differ significantly from the assumptions employed here. The direction of bias in this case may be to underestimate costs.

Another potential source of bias in retained heat cooker costs is the valuation of insulation materials. In the present analysis, insulation materials are based on imported polystyrene beads imported from South Africa. BRET staff have experimented with less expensive insulation materials, with the result that production unit costs may be overestimated if largely local materials are used.

On the benefits side, two potential sources of bias are household safety and environmental protection. As in the case of BRET stoves, retained heat cookers do provide some protection from the hazards of open fire cooking. However,depending on the insulation materials used, they may also pose a risk in terms of potential spontaneous combustion. Because of limited user experience, it has not been possible to determine whether the benefits of protection from open fire cooking are offset by the risk of spontaneous combustion, with the result that the potential direction of bias in this case is indeterminate. As to environmental protection, to the extent that retained heat cookers conserve fuelwood energy, they provide a benefit to society at large, a factor that should be considered in the context of an economic analysis of retained heat cookers. However, because of the diffuse nature of this social benefit, no attempt has been made to incorporate it into the analysis, with the result that the benefits of the retained heat cooker may be underestimated.

Given the economics of the retained heat cooker, because the BRET cheaper model still costs almost P12.00, the primary market for this technology is likely to be in urban areas. As in the case of the BRET stove, there are some 60,000 urban households that comprise the potential market for retained heat cookers. While the growth of this market is expected to be substantial over the next six years, without

Table 14

Value of Base Year Annual Savings from BRET Retained Heat Cooker

For 1985 Botswana's national fuelwood consumption is expected to be at 174l160 tonnes of oil equivalent. At .35 physical tonnes of fuelwood per tonne of oil equivalently this is equivalent to 497l600 tonnes of fuelwood which when divided by the projected 1985 population yields a per capita annual level of fuelwood consumption of .4539 tonnes or 1.24 kg per day. With an estimated household size of 5.81 persons this translates into a daily household consumption of fuelwood of 7.2251 kg, which on an annual basis yields 2637.17 kg of fuelwood. In the table below alternative possible levels and values of fuelwood savings obtainable by a household's purchase of a BRET retained heat cooker are given for purposes of economic evaluation. In all cases the reference is in terms of the quantity and value of savings in terms of the no-retained heat cooker case of 2637.17 kg of fuelwood per household per year.

1. Percentage Usage of RHC:	10%	25%	50%	75%	100%
2. Quantity of Wood Energy Saved per year, in kg.	39.74	99.34	198.68	298.02	397.36
3. RHC Wood Energy Savings as a Percentage of Household Annual Wood Energy Consumption:	1.5%	3.8%.	7.5%	11.3%	15.1%.
4. Annual Pula Value of Fuelwood Saved with Kg price at:					
a. 3 thebe	1.19	2.98	5.96	8.94	11.92
b. 4 thebe	1.59	3.97	7.95	11.92	15.89
c. 5 thebe	1.99	4.97	9.93	14.90	19.87

Sources: The range of price estimates has been based on sample fuelwood prices reported in recent energy surveys conducted throughout Botswana (Oki 1984, Gay 1985, ODA 1985). The range of fuelwood savings potential of the BRET retained heat cooker has been based performance data from BRET technical tests listed in Table 12.

Table 15

Sensitivity Analysis of BRET Retained Heat Cookers

(based on financial analysis and 100 percent use rate)

	With the Opportunity Cost of Extra Cooking Time Per Hour Valued at:			
I. **Basic Assumptions**:	**0 thebe**	**.5 thebe**	**I thebe**	**1.5 thebe**
A. 0 Rate of Increase In Real Fuelwood Price				_
B. 6 % Discount Rate				
C. 3 thebe per kg/wood				
D. 397.36 kg wood saved				
E. RHC Model:				
1. BRET Del.Prod.Cost				
a. Price: P11.78				
b. Results:				
i. NPV	13.03	3.91	-5.21	-14.33
ii. IRR	Positive	85.51%	Negative	Negative
iii. B/C ratio	1.62	1.18	0.74	0.30
2. South African Comm.Model				
a. Price: P16.00				
b. Results:				
i. NPV	8.81	-0.30	-14.43	-18.55
ii. IRR	139.43%	3.07%	Negative	Negative
iii. B/C	1.35	0.98	0.62	0.25
II. **Basic Assumptions**:				
A. 0 Rate of Increase In Real Fuelwood Price				
B. 6% Discount Rate				
C. 4 thebe per kg/wood				
E. RHC Model:				
1. BRET Del.Prod.Cost				
a. Price: P11.78				
b. Results:				
i. NPV	24.28	15.16	6.02	-3.08
ii. IRR	Positive	Positive	161.10%	-34.64%
iii. B/C ratio	2.17	1.73	1.29	0.85
2. South African Comm.Model 1				
a. Price: P16.00				
b. Results:				
i. NPV	20.06	10.94	1.80	-7.30
ii. IRR	9,678.61%	203.62%	24.62%	-137.36%.
iii. B/C	1.80	1.43	1.07	0.70

III. **Basic Assumptions:**
- A . 0 Rate of Increase
  in Real Fuelwood Price
- B. 6 % Discount Rate
- C. 5 thebe per kg/wood
- D. 397.36 kg wood saved
- E. RHC Model:
  - 1. BRET Del.Prod.Cost
    - a. Price: P11.78
    - b. Results:

i. NPV	35.56	26.43	17.30	8.19
ii. IRR	Positive	Positive	Positive	305.59
iii. B/C	2.71	2.27	1.83	1.39

  - 2. South African Comm. Model
    - a. Price: P16.00
    - b. Results:

i. NPV	31.34	22.21	13.09	3.97
ii. IRR	Positive	Positive	304.24%	50.98%
iii. B/C	2.25	1.89	1.52	1.15

With the Opportunity Cost of Extra Cooking Time
Per Hour Valued at:

0 thebe	**.5 thebe**	**1 thebe**	**1.5 thebe**

IV. **Basic Assumptions**:
- A. 5 % Rate of Increase
  in Real Fuelwood Price
- B. 6 %. Discount Rate
- C. 3 thebe per kg.'wood
- D. 397.36 1(9 wood saved
- E. RHC Model:
  - 1. BRET Del.Prod.Cost
    - a. Price: P11.78
    - b. Results:

i. NPV	14.68	5.56	-3.57	- 12.06
ii. IRR	Positive	113.72%-34.04	Negative	
iii. B/C	1.70	1.26	0.82	0.41

  - 2. South African Comm. Model
    - a. Price: P16.00
    - b. results:

i. NPV	10.43	1.34	-7.78	-16.28
ii. IRR	158.50%.	18.23%	-141.99%	Negative
iii. B/C	1.41	1.05	0.68	0.34

V. **Basic Assumptions**:

A. 5 % Rate of Increase
in Real Fuelwood Price
B. 6 % Discount Rate
C. 4 thebe per l(g/wood
D. 397.36 Kg.wood saved
E. RHC Model:
1. BRET Del.Prod.Cost
a. Price: P11.78
b. Results:

i. NPV	26.48	17.36	8.22	-0.88
ii.IRR	Positive	Positive	206.04%	-4.59%
iii.B/C	2.27	1.83	1.39	0.95

2. South African Comm .Mode1

i. NPV	22.26	13.14	4.00	-5.10
ii. IRR	10,407.63%	234.61%	45.25%.	-31.58%
iii. B/C	1.89	1.52	1.16	0.79

VI. **Basic Assumptions**:

A. 5 % Rate of Increase
in Real Fuelwood Price
B. 6 % Discount Rate
C. 5 thebe per Kg/wood
D. 397 . 36 kg .wood saved
E. RHC Model:
1. BRET Del.Prod.Cost
a. Price: P11.;78
b. Results:

i. NPV	38 . 25	29 . 12	19 . 99	10 . 88
ii. IRR	Positive	Positive	Positive	375.32%
iii. B/C	2.84	2.40	1.96	1.52

2. South African Comm. Model
a Price: P16.00
b. Results:

i. NPV	34.03	24.90	15.77	7.27
ii. IRR	Positive	Positive	347.21%	86.14
iii.B/C	2.36	1.99	1.63	I.29

Table 16

Sensitivity Analysis of BRET Retained Heat Cookers - Il

Listed below are sensitivity test results for the BRET retained heat cooker based on a financial analysis, a zero opportunity cost of extra cooking time, and variable assumptions regarding the percentage of cooking that is done with the retained heat cooker.

		With Per kg Fuelwood Eneroy Savings Valued at:								
		3 thebe			**4 thebe**			**5 thebe**		
		NPV	**IRR**	**B/C**	**NPV**	**IRR**	**B/C**	**NPV**	**IRR**	**B/C**
I. **Basic Assumptions**:										
A. Zero Rate of Annual Increase in Real Fuelwood Price										
B. Percentage of Meals Cooked with RHC:										
1	100%	14.7	Pos.	1.76	25.9	Pos.	2.35	37.2	Pos.	2.94
2.	75%	6.2	295%	1.32	14.7	Pos.	I.76	23.1	Pos.	2.20
3.	50%	-2.3	-32%	0.88	3.4	100%	1.17	9.0	2045%	1.47
4 .	25%	-10.7	Neg.	0.44	-7.9	Neg.	0.58	-5.0	Neg.	0.73
5.	10%	-15.7	Neg.	0.17	-14.7	Neg.	0.23	-13.5	Neg.	0.2
II. **Basic Assumptions**:										
A. Five Percent Rate of Annual Increase in Real Fuelwood Price										
B. Percentage of Meals Cooked With RHC:										
1.	100%	16.3	Pos.	1.85	28.1	Pos.	2.47	39.9	Pos.	3 08
2.	75%	7.5	339%	1.39	16.3	Pos.	1.85	25.2	Pos.	2 31
3.	50%	-1.4	-17%	0.92	4.5	125%	1.23	10.4	2269%	1.54
4.	25%	-10.3	Neg.	0.46	-7.3	Neg.	0.61	-4.3	Neg.	0.77
5.	10%	-15.6	Neg.	0.18	-14.4	Neg.	0.24	-13.2	Neg.	0.30

Table 17

BRET Retained Heat Cooker
Financial Analysis

	Period:	1.00	2.00	3.00
A. **Model: BRET RHC "Wonderbox" Assumptions**:				
1. **Technical parameters**:				
a.Annual Wd.Eq..Energy Saving	7%			
b. RHC life	3.00			
c. Replace box frame	2.00			
d. Replace cloth liner	2.00			
e. Replace top	2.00			
f. HH Kg/p.a. Wd.En.saved		198.68 = 50 percent Use		
2. **Economic parameters**	Rate			
a. Discount rate		.06		
b. Shadow wage rate		1.00		
c. Shadow For.Exch. rate		1.00		
d. RHC Selling Price		16.00		
e.Ann.Rate Wd.Eq..Price Increase		0 Percent		
f.Price per Kg.Wd.En.Equiv.		5 thebe		
B. **Costs**:	Pula:			
1. BRET RHC Selling Price	16.00	16.00		
2. Replacement box frame	4.50	4,50		
3. Replacement cloth liner	3.75	3.75		
4. Replacement top	1.50	1.50		
5. **Annual Cost Flow**		16.00	5.25	4.50
6. **Discounted Annual Costs**	16.00	4.95	4.00	
7. **Present Value of Costs**		24.96	Pula	
C. **Benefits**		Pula:		
1. Value of Wd.En.Equiv.saved	9.93	9.93	9.93	9.93
2. Value of Added Cooking Time	.00	.00	.00	.00

3. **Annual Benefit Flow**	9.93	9.93	9.93
4. **Discounted Annual Benefits**	9.93	9.37	8.84
5. **Present Value of Benefits**	28.14	Pula	

Financial Evaluation:

1. **Net Present Value**	3.18	Pula
2. **Internal Rate of Return**	40.69	Pct.
3. **Benefit-Cost Ratio**	1.13	

Note: RHC selling price based on BRET Delivered Production Cost

more information on how retained heat cookers would be used by Batswana households, it is not clear that this technology would qualify for continued public support. However, since there are potential energy savings on the order of fifteen percent of household consumption, a modest program of continuing research and development on the economics of this technology should be investigated.

V. **BRET Small Batch Solar Hot Water System**

A. Conceptual Issues in the Analysis of the BRET Small Batch Solar System

As part of BRET s mandate, staff have devoted some effort to the development of a small batch solar hot water system. Designed to conserve on the consumption of fuelwood energy primarily by rural households, the small batch system is a non-insulated black wooden box with a removable transparent plastic glaze in which one can insert three black five-liter containers of water. Although there is some experience with small batch systems elsewhere, the BRET model represents an attempt to develop a low cost model that could readily satisfy rural hot water demand while achieving significant savings of fuelwood energy, yet, as the following analysis will show, the BRET batch hot water system does not at present appear to be economically competitive from either a financial analysis or an economic analysis perspective. Although BRET staff had reached this basic conclusion in 1984, they decided to continue to work with the model in order to develop cost information, a better understanding of hot water demand, and how rural communities would respond to solar hot water technology. For this reason, the experience gained thus far from the BRET system should be considered as a base line study for any further research and development efforts that Batswana authorities may wish to pursue in the future.

It should be noted at the outset the traditional ways that Batswana rural households prepare hot water. One is direct hot water heating over an open fire with a three-legged pot. Another is by placing a tin of water adjacent to a three-legged pot while cooking and other household energy functions are being performed. If a household heats hot water only in tins adjacent to cooking pots, the joint thermal efficiency of household energy use is likely to be enhanced since the tin is absorbing largely rejected cooking energy from the open-fire system. However, there is thus far only limited evidence of the distribution of these functions among Batswana households so that one could better estimate the potential energy savings of a small batch solar hot water system.

Limited data on household energy use have required a somewhat complicated procedure for the assessment of the BRET small batch solar hot water system. It it not just that there are limited data on traditional methods of hot water preparation. It is also that there is limited information on hot water temperatures from traditional methods as well as on the level of household hot water consumption. For these reasons, the procedure used in the analysis has been to take the performance data of small batch system, in which temperatures and physical quantities are known, and then impute these temperature levels to actual household hot water consumption. In addition, as pointed out in the discussion of the BRET stove! because evidence on the distribution of household energy consumption is also limited, estimation of the potential wood energy savings from the small batch system has been based on a variety of assumptions regarding the proportions of household energy devoted to the preparation of hot water, as well as assumptions regarding the thermal efficiency of traditional open-fire systems. From these steps, estimates of the potential fuelwood energy savings possible from use of the small batch system at varying degrees of its capacity have then been made.

B. Estimation of Small Batch Solar Hot Water Unit Costs

As in the development of the retained heat cooker, the BRET small batch solar hot water system has had only limited production experience. Only thirty units were produced during the March 1983 to May 1984 period, and in each case, the method of production was through workshop participation in which trainees were permitted to acquire the small batch system at a nominal materials cost charge of P12.00 upon completion of the workshop. As can be seen in the unit cost estimates of Table 18, the focal points of workshop production have been in Shoshong and Ditshegwane, as well as in Mahalapye, Molepolole, and Mookane. For this reason, these unit cost estimates reflect a largely artisan-based production system in which no attempt has been made to transfer production to these artisans on a continuing basis for purposes of direct commercialization. Moreover, it should also be pointed out that workshop participants were largely unskilled, in which case costs were higher than they would have been had BRET chosen already skilled workers for workshop participation.

Table 18 lists two basic unit cost estimates, one being a delivered production unit cost, which is appropriate to a financial analysis, and the other being the total R and D unit cost, which is appropriate to an economic analysis. As in the analysis of the BRET stoves and the retained heat cookers, the primary unit cost figure that has been used is the delivered unit production cost, as this corresponds most closely to a financial analysis variable.However, because even this figure is almost as expensive as recent estimates of household conventional solar hot water systems, one additional unit cost figure has been used, namely, a P40.00 hypothetical figure that would more closely approximate the unit performance level of a low cost system. It should be noted that the P40.00 figure in no way represents any actual BRET estimate. It is simply an attempt to consider the economics of the batch system were it to be produced under a more commercially defined production environment.

C. Estimation of Small Batch Solar Hot Water Benefits

As noted in section A, there are limited data on consumption of hot water in Botswana. For this reason, the estimation of benefits from the small batch solar hot water system has proceeded in several steps. The first step has been to estimate the level of hot water demand among Botswana households. The only readily available estimate is one made by BRET staff as part of a rural energy survey conducted in 1984, the results of which are reported in Table 19. As one would expect, household hot water demand is greater in the winter than in the summer (by a greater than sixty percent margin), with most hot water being consumed in the evening. For purposes of analysis, an estimated 27.99 litres per household per day has been used as a seasonally adjusted figure.

Given the estimate of household hot water demand, the next step in the estimation of the benefits of the small batch solar hot water system is the calculation of performance levels. Data on tests conducted by BRET staff in 1982 and 1983 indicate that the small batch solar hot water system in the typical climatic environment of Botswana can raise temperatures from between 14.5 and 35.0 degrees Celsius, with first law thermal efficiencies of between thirty-six and thirty-nine percent. These test results are listed in section of Table 20.

Based on the technical performance of the small batch solar hot water system, the next step is to construct an estimate of the amount of fuelwood energy savings possible from use of the system. The calculations for this estimate are shown in sections B and C of Table 20. What is required to do so is to calculate the amount of energy needed to raise the temperature of the water from a small batch solar hot water system in proportion to the actual temperature increases, both on a theoretical level as well as on a practical level in which the first law thermal efficiency of energy conversion has been taken into account. Then, based on variable proportions of the household energy budget devoted to the preparation of hot water, as well as based on varying assumptions regarding the thermal efficiency of an open fire system, if one makes the somewhat heroic assumption that the temperatures achieved from the small batch solar hot water system are equivalent to those obtained from traditional methods of preparing hot water, then the estimated amount of fuelwood necessary to satisfy household hot water demand ranges from between just under 400 kg to just under 800 kg of wood per household per year.

The next step in the derivation of benefits is to take the open fire thermal efficiency of a conventional hot water system and then calculate the wood energy consumption displaced by use of the small batch solar hot water system if the small batch solar hot water system is used at rates ranging between ten and one hundred percent of its capacity. This is done in sections C and D of Table 20. It should be pointed out that even if the small batch system is used at one hundred percent of its capacity that the amount of fuelwood energy savings would represent at most a fifty-four percent savings of fuelwood energy since the 15 liter capacity of the system is only that proportion of the 27.99 liter daily hot water demand among Batswana households.

From the derivation of potential fuelwood savings, the final step in the estimation of benefits from the small batch solar hot water system is the multiplication of quantity savings times various per Kg wood energy prices. The resulting matrix of benefit values is listed under section D of Table 20. Although one could also consider the value of reduced fuelwood collection time for those communities where fuelwood markets are not fully developed, the values listed in section D of Table 19 constitute the principal benefit stream used in the analysis.

Table 18

BRET Batch Solar Hot Water Heater
Unit Costs, in Pula

(March 1983 - May 1984)

Item:	**Total**	**Mahalapye, Molepolole, Mookane Unit Cost:**	**Shoshong, Ditshegwane Unit Cost:**
1. **Materials**:			
a. chipboard(2.4m x 1.2m x 16mm)	23.79	1.70	1.70
b. planking(38m x 152m x 2.2mm)	1.95/m	4.29	4.29
planking(25m x 50m x 2.2mm)	0.98/m	2.15	2.15
c. glazing	l0/sq.m5.00	5.00	
d. hinges	0.50	1.00	1.00
e. latches	0.40	.80	.80
f. wood glue (5 liter)	3.30	.22	.22
g. black matte paint (5 liter)	9.11	.91	.91
h. white spirits (5 liter)	10.69	2.14	2.14
i. nails (kg)	1.50	.15	.15
Sub-Total for Materials:		**18.36**	**18.34**
2. **Labor**:			
a.Mahalapye,Molepol.,Mookane:(17units)			
(av.construction time: 13 hrs./part.)			
i. Extension Worker Training:			
3.66/hr/instructor x 3.06 hours/unit	190.39	11.20	
ii. Extension Worker Participation:			
2.00/hr/part x 13 hours x 3 per unit	234.00	78.00	
(i.e.,approx.3 parts. per unit)			
b. Shoshong and Ditshegwane:(13 units)			
i. village Worker Training:			
(3.66/hr)(3.77hrs/'unit)+(4.55./hr)(4hr/U)	416.00		32.00
ii. Village Worker Participation:			
(7days/part.)(2.00/day)(19 participants)	266.00		20.46
or, based on daily minimum wage:			
(7days/part.)(5.00/day)(19 participants)	665.00		51.15
			52.46
Sub-Total for Labor:		**89.20**	**83.15**

3. **Tools**:			
a.five 500 gr.claw hammers a 12.50 each:	62.50		
i.annualized unit cost(per 10 yr.life):		.21	.21
b.five (600x8pt.) cross cutting saws, a 8.61 each:	43.05		
i.annualized unit cost (per 10 yr.life):		.14	.14
c. two wood drills w/braces a 36.81 ea.:	73.72		
i.annualized unit cost/per 10 yr.life):		.25	.25
d.four drill bits a 15.00 each:	60.00		
i.annualized unit cost(per. 1 yr.life):		2.00	2.00
e. one 3 meter tape a 6.60 each:	6.60		
i.annualized unit cost(per 3 yr. life):		.07	.07
f. two pairs of scissors a 10.00 each:	20.00		
i.annualized unit cost(per 3 yr. life):		.22	.22
g. 3 screwdrivers a 3.00 each:	9.00		
i.annualized unit cost(per 5 Yr. life):		.06	.06
h. five 1.5" paintbrushes a 4.00 each:	20.00		
i.annualized unit cost(per 1 yr. life):		.67	.67
i. two carpenter's squares a 5.81 each:	11.62		
i. annualized unit cost(per 1 yr. life):		.39	.39
Sub-Total for Tools:		**3.80**	**3.80**
4. **Material transport**			
a. Mahalapye,Molepolole,Mookane (4x200x.42+2xl00x.42+2x55x.42)	466.20	27.42	
b. Shoshong, Ditshegwane (2x242x.42+2xl35x.42)	324.78		60.84
5. **Delivered Production Cost** (financial analysis variable)		**138.78**	**166.15**
6. **Promotion labor cost**			
a.Mahalapye,Molepolole,Mookane (90+37.5+22.5)(4/day):		600.00	
b. Shoshong, Ditshegwane (28+36)(4/day):			256.00
7. **BRET staff overhead cost**: (90,583x.03)/(30):		90.58	90.58
8. **Development Cost**		**690.58**	**346.58**
9. **Total R and D Unit Cost** (5. + 8.); (economic analysis variable)		**829.36**	**512.73**

Source: BRET staff data. As all units were constructed by participants in workshops and participants were charged only a P12.00 materials cost, there is no equivalent market sale price. Similarly, because training wa based only on a total of 30 units produced in all centers, delivered production unit costs for the financial analysis are higher than what they would be in a market production environment.

Table 19

Daily Hot Water Demand in Rural Communities in Botswana

I. **Seasonal Quantity Distribution per Household:**

Quantity (in litres)		**5**	**5**	**10**	**15**	**≥20**
A. **Summer**						
Morning		-	9.2%	-	-	-
Mid-Morning	-	12.8	-	-	-	
Afternoon	-	11.0	-	-	-	
Evening		-	67.0	100.0%	100.0%	-
Total		-	100 0%	100.0%	100 0%	-
Frequency:		-	94.0%	1.7%	4.3%	-

Weighted Average Quantity of Daily Household Demand in Summer: 21.33 L.

Weighted Average Quantity of Daily Per Capita Demand in Summer: 3.67 L.

	5	**5**	**10**	**15**	**≥20**
B. **Winter**					
Morning	32.5%	39.4%	48.4%	55.6%	40.0%
Mid-Morning	30.3	17.7	20.4	11.1	6.7
Afternoon	12.4	14.7	14.8	-	20.0
Evening	24.7	28.2	16.7	33.3	33.3
Total	100%	100.0%	100%	100 0%	100 0%
Frequency	18.0%	66.2%	10.9%	1.8%	3.0%

Weighted Average Quantity of Daily Household Demand in Winter: 34.65 L.

Weighted Average Quantity of Daily Per Capita Demand in Winter: 6.18 L.

II. **Seasonal and Annual Aggregate Household Demand Hourly Distribution**:

	Summer	Winter	Annual
Morning	8.6%	39.5%	24.1%
Mid-Morning	12.1	19.8	16.0
Afternoon	10.3	14.2	12.3
Even i ng	69.0	26.5	47.6
Totals	100.0%	100.0%	100.0%
Daily Quantity per HH:	21.33	34.65	27.99 Litres.
Daily Quantity per Cap:	3.67	6.18	4.93 Litres.

Source: BRET staff Extension Unit data summarized in memorandum of August 16, 1984, based on surveys in Ditshegwane and Shoshong. In terms of total water demand, data provided from BRET pumping program source estimates indicate that seasonally adjusted daily consumption is on the order of 24.73 litres per capita, based on February 1985 data from: Malatswana, Oodi, Bonwapitse, Taupye, Good Hope, and Ranaka. Given that the mean size of households is between 5.81 and 5.95 persons, total household water consumption is on the order of 147-14 litres per day In terms of hot water demand, the above annual household demand thus represents approximately 19 percent, which is consistent with the proportion of energy used by households for water heating, dish washing, bathing, and clothes washing, the principal non-cooking demand for hot water. Cf. John Gay, *Urban Energy Survey, in Serowe, Palapye, Molepolole, Selibe-Phikwe, Lobatse and Gaborone*. (Burlington, Vermont: ARD, Inc., for U.S. AID contract 633-0209-C-00- I 024-00, January, 1985), p . 50, Table 39 .

Table 20

Performance Data for Non-lnsulated BRET Batch Solar Hot Water Heater

A. **Performance**:

Test Sample Date:	**Ambient Temp.**	**Water Volume**	**Water Temperature**		**Temperature Increase**	**Time:**		**Efficiency**
			In	Out		**In**	**Out**	
1. 12/82	30.0	10 L.	28.5	43.0	14.5	10:50	14:20	36 %
2. 7/83	18.5	10 L.	15.0	50.0	35.0	9:00	16:00	39 %
3. **Average**:								**37.5** %

B. **Theoretical Solar Hot Water-Wood Energy Relationships**:

(at 100% efficiency, in Wood Energy Equivalent)

1. **Seasonal Wood Energy Requirements Necessary to Satisfy Hot Water Demand**

a. **Summer**: Q = (10)(14.5 deg.)(4180j/kg)(10exp-6mj/j)(kg/14.6mj) = .041513699 kg wood for every 10 litres of water whose temperature is raised by 14.5 degrees Celsius in an ambient temperature environment of approximately 30 degrees Celsius.

i. Estimated summer household daily hot water demand: 21.33 litres.

ii. Estimated summer household daily wood energy required to satisfy daily household hot water demand (at 100%. efficiency):
(21.33X10 litres)(.0415) = .088548 kg. wood energy equivalent.

iii. Estimated hot water available per kg. of wood energy equivalent (at 100% efficiency):
(21.33X.088548) = 240.88 Litres per Kg. wood energy equivalent

iv. Estimated summer household seasonal (6 months) wood energy required to satisfy seasonal household hot water demand (at 100% efficiency):
(21.33X10 litres)(.0415)(6)(30) = 15.94 kg. wood energy eq.

b. **Winter**:Q = (10)(35 deg.)(4180j/kg)(10exp-6mj)(1kg/1kg/14.6mj) = .1002054795 kg wood for every 10 litres of water whose temperature is raised by 35 degrees Celsius in an ambient temperature environment of approximately 18.5 degrees Celsius.

i. Estimated winter household daily hot water demand: 34.65 litres.

C. Estimated winter household daily wood energy required to satisfy daily household hot water demand (at 100% efficiency):
(34.65X10)(.10) = .347212kg. wood energy equivalent.

D. Estimated hot water available per kg. of wood energy equivalent (at 100% efficiency):
(34.65X.34212) = 99.7949 litres per kg.wood energy equivalent

E. Estimated winter household seasonal(6 months) wood energy required to satisfy seasonal household hot water demand (at 100% efficiency):
34.65X10 litres(.10)(6)(30) = 62.498157 kg.wood energy eq.

2. **Seasonally Adjusted**:
    a. **Daily adjusted household hot water demand**:
    (21.33 + 34.65)X2 = 27.60 Litres
    b. **Daily household energy required to satisfy daily household hot water demand** (at 100%. efficiency): (.089 + .347)X2 = .218 kg. wood energy equivalent
    c. Litres of hot water available per Kg. of wood energy equivalent
    (at 100 % efficiency)
    (27.99)/.218 = 128.45 Litres.
    d. Estimated wood energy equivalent energy needed to satisfy annual
    household hot water demand (at 100% efficiency)
    (15.94 + 62.49) = 78.44 Kg. wood energy equivalent.
    e. Estimated annual household hot water available per Kg.
    of annual wood energy equivalent consumption (at 100% efficiency)
    (128.45)(78.44) = 10,075.50 litres.

C. **BRET Batch Solar Water Heater Potential Savings in Terms of Household Hot Water Demand**:

1. **Open Fire Wood Equivalent Hot Water Wood Energy Consumption as a Function of Total Annual Household Wood Energy Consumption**:
   a. **Estimated annual consumption of wood energy per household**:
   2680 Kg. per annum.
   b. **Amount of wood used for hot water if wood budget at the following percentages of total annual wood energy equivalent consumption**:

	10%	20 %	30 %
i. Kg. of wood	268	536	804

   c. Quantity of hot water from open fire wood equivalent system if system has the following thermal efficiencies (i.e., Kg of wood equivalent energy times liters of water per Kg of wood equivalent energy times the thermal efficiency of the wood equivalent energy system), e.g. at a ten percent hot water.wood equivalent energy budget, if the open fire system is ten percent efficient, the amount of hot water available would be: (268)(128.45)(.10) = 3442.46 litres.

Wood Budget at:

	10%	20%	30%
kg.	**268**	**536**	**804**
i. **Litres of Hot Water per year with Open Fire Thermal Efficiencies of**:			
10 %.	**3,442.46**	**6,884.92**	**10,327.38**
20 %.	**6,884.92**	**13,769.84**	**20,654.76**

ii. **Litres of Hot Water per Kg. of wood with Open Fire Thermal Efficiencies of**

10 % :	**12.845 litres**
20 % :	**25.690 litres**

Since household annual hot water demand is estimated at 10,075.50 litres, the corresponding wood energy consumption necessary to satisfy this demand for an open fire equivalent system with thermal efficiencies of between 10 and 20 percent ranges from between 392.19 kg (at 20. efficiency) and 784.39 Kg (at 10% efficiency) of wood equivalent energy per Year.

2. **BRET Batch Solar Hot Water Wood Energy Savings Potential**
   1. **Theoretical Efficiency**:
      a. A single 15 liter unit operating at 100 percent of capacity can provide 5,475 litres of hot water per year.
      b. At 100 percent efficiency, and at 128.45 litres per Kg of wood equivalent energy, the theoretical wood energy savings from the batch solar hot water system would be: (5,475)/(128.45) = 42.62 Kg. of wood (or 54.34 percent of the 78.44 Kg. of wood necessary to satisfy household annual hot water demand (at 100 percent efficiency)

2. **Practical Efficiency:**

Since a 15 liter BRET batch solar hot water unit can satisfy 54.34 percent of an open fire wood energy equivalent system, the potential wood energy savings potential from the use of the Solar hot water system can be expressed as the Kg. of wood displaced as a fraction of the BRET batch unit capacity for the two comparative open fire thermal efficiency wood energy requirements:

Hot Water Wood Demand With Open Fire Efficiencies of:	10 %	20%
i. Wood Displaced if BRET batch solar unit operated at the following percentages of the 5,470 liter annual capacity (in Kg.)		
10 %	**42.6**	**21.3**
25 %	**106.6**	**53.3**
50 %	**213.2**	**106.6**
75 %	**319.8**	**159.9**
100 %	**426.4**	**213.2**

D. **Value of Wood Equivalent Energy Savings from BRET 15 Liter Solar Hot Water Unit per Year:**

1. **With Open Fire Wood Energy Equivalent Thermal Efficiency of 10 percent**:

Annual Savings in Pula With Price per Kg. of Wood at:

Fraction of BRET Unit Annual Capacity:	**3 thebe**	**4 thebe**	**5 thebe**
10%	**1.28**	**1.71**	**2.13**
25%	**3.20**	**4.26**	**5.33**
50%	**6.40**	**8.53**	**10.66**
75%	**9.59**	**12.79**	**15.99**
100%	**12.79**	**17.06**	**21.32**

2. **With Open Fire Wood Energy Equivalent Thermal Efficiency of 20 percent**:

Fraction of BRET Unit Annual Capacity:			
10%	**0.64**	**0.85**	**1.07**
25%	**1.60**	**2.13**	**2.67**
50%	**3.20**	**4.26**	**5.33**
75%	**4.80**	**6.40**	**8.00**
100%	**6.40**	**8.53**	**10.66**

Source: BRET Staff field test data. The wood energy equivalents are based on the specific heat of water at 4,180 joules per Kg. per degree Celsius, and on the heat value of wood energy at 14.6 megajoules per Kg. No allowance has been made for actual temperature differences between the quantity of hot water consumed by households using open fire systems with that provided by the

BRET batch solar hot water system as no data have been available on average hot water temperatures obtained by traditional open fire equivalent hot water energy systems. The thermal efficiency of the Batch solar hot water unit has been calculated on the basis of the quantity of direct normal solar energy received on the approximately .2 sq.meter surface of the solar hot water unit during the given hourly times of the year as a fraction of the energy embodied in the increased temperature of the volume of water heated.

D. **Sensitivity Analysis of BRET Small Batch Solar Hot Water Systems**

Sensitivity tests conducted on the BRET small batch system are summarized in Table 21, along with a sample output reported in Table 22. Using the BRET delivered production unit cost as the principal capital cost figure, the life cycle cost for the small batch solar hot water system financial analysis has been based on several basic operating assumptions. One is that the system will have an economically useful lifetime of ten years, of which only the box frame will last that long. Another is that the glaze and the chipboard bottom would have to be replaced each year, based on moderate to heavy use of the system.

The tests reported in Table 21 point to one basic conclusion, namely, that in order to be economic from a financial analysis perspective, the price of fuelwood would have to be at a minimum level of just under 4 thebe per kg, and with the constraint that the typical household would use the system at least at a seventy-five percent capacity utilization rate. These conditions thus tend to rule out the economics of the small batch system for the originally intended market, viz., rural households. What also rules out the smallbatch system is the initial capital cost, especially given lively rates of time preference of individual households. This is true even if one abandons the BRET delivered unit cost price of P138.78 reported in Table 18 in favor of a hypothetically more efficient capital cost of P40.00, which still constitutes a substantial proportion of rural household cash income. In terms of policy, then, what these results imply is that under present conditions, the small batch solar hot water system is not economic. However if one could develop a more cost-effective unit, then perhaps a more promising market could emerge. In conclusion, no further public support of developmental efforts of this system appears warranted at this time.

Table 21

Sensitivity Analysis of BRET Batch Solar Hot Water Unit

	Value of Fuelwood Saved at a Per Kg. Price of:			
	3 thebe	**4 thebe**	**5 thebe**	**Test Limit value**
1. **Basic Assumptions**:				
A. 15 Liter Batch Unit Price: P138.78 (Delivered Production Cost)				
B. Capacity Utilization Rate of BRET Batch Unit: 75 %				
C. Thermal Efficiency of Open Fire Equivalent System: 10 %				
D. Discount Rate: 6 %				
E. Basic Results:				
i. **NPV**	-135.27	-104.59	-73.92	
ii. **IRR**	neg.	-18.23	-9.12	
iii. **B/C**	0.40	0.54	0.67	
F. **Minimum Necessary Price of Fuelwood per Kg. to Make BRET Batch Unit Economic at**:				
i. 100 % of BRET capacity				5.56 thebeKg.
ii. 75 % of BRET capacity				7.41 thebeKg.
iii. 50 % of BRET capacity				11.12 thebeKg.
II. **Basic Assumptions**:				
A. 15 Liter Batch Unit Price: P40.00 financial analysis variable)				
B. Capacity Utilization Rate of BRET Batch Unit: 75 •%.				
C. Thermal Efficiency of Open Fire Equivalent System: 10%				
D. Discount Rate: 6 %				
E. Basic Results:				
i. **NPV**	- 53.57	-28.63	-8.67	
ii. **IRR**	neg.	neg.	2.34	
iii. **B/C**	0.58	0.77	0.97	
F. **Minimum Necessary Price of Fuelwood per Kg. to Make BRET Batch Unit Economic at**:				
i. 100 % of BRET capacity				3.86 thebe/Kg
ii. 75 %. of BRET capacity				5.05 thebe/'kg
iii. 50 % of BRET capacity				7.72 thebe/Kg

III. **Basic Assumptions**:

A. 5 Liter Batch Unit Price: P40.00
(financial analysis variable)

B. Capacity Utilization Rate of BRET Batch Unit: 75 %

C. Thermal Efficiency of Open Fire Equivalent System: 20%.

D. Discount Rate: 6 %

E. Basic Results:

i.	**NPV**	-82.4	-67.67	-51.73
ii.	**IRR**	neg.	neg.	neg.
iii.	**B/C**	0.35	0.47	0.59

F. **Minimum Necessary Price of Fuelwood per Kg/. to Make BRET Batch Unit Economic at**:

i.	100 % of BRET capacity	7.72 thebe/Kg
ii.	75 % of BRET capacity	10.30 thebe/Kg
iii.	50 % of BRET capacity	15.44 thebe/kg

Table 22

BRET Batch Solar Hot Water Heater
Financial Analysis

	Period	0	1	2	3	4	5	6	7	8	9
A. **Model: BRET 15 Litre Solar Unit**											
1. Technical parameters	**Assumptions**										
a. BRET capacity use rate:	75.00%										
b. Life of BRET Batch Solar Unit	10 years										
c. Replace glaze:	yearly, annual increase in real price at:						0 percent.				
d. Replace chipboard:	yearly, annual increase in real price at:						0 percent.				
e. kg. fuelwood saved:	267.99										
2. Economic parameters											
a. Discount rate	0.06										
b. Shadow wage rate	1										
c. Shadow Foreign Exchange rate	1										

d. BRET BSHW Selling Price	40										
e. Ann. Rate Wood Price Increase	0.05	percent									
f. Price per kg. of firewood	5	thebe									
B. **Costs:**											
1. BRET BSHW Purchase Price:	40	40									
2. Replace glaze:	8		8	8	8	8	8	8	8	8	8
3. Replace chipboard:	5		5	5	5	5	5	5	5	5	5
4. Annual Cost Flow		40	13	13	13	13	13	13	13	13	13
5. Discounted Annual Costs		40	12.26	11.57	10.92	10.30	9.71	9.16	8.65	8.16	7.69
6. Present Value of Costs	**128.42**	Pula									
C. **Benefits:**											
1. Value of fuelwood saved:	13.40	13.40	14.07	14.77	15.51	16.29	17.10	17.96	18.85	19.80	20.79
2. Value of boiling time saved:	0	0	0	0	0	0	0	0	0	0	0
3. Annual Benefit Flow		13.40	14.07	14.77	15.51	16.29	17.10	17.96	18.85	19.80	20.79
4. Discounted Annual Benefits		13.40	13.27	13.15	13.02	12.90	12.78	12.66	12.54	12.42	12.30
5. Present Value of Benefits	**128.45**	Pula									
D. **Undiscounted Cash Flow**		-26.60	1.07	1.77	2.51	3.29	4.10	4.96	5.85	6.80	7.79
E. **Evaluation:**											
1. Net Present Value	0.02	Pula									
2. Internal Rate of Return	6.02	percent									
3. Benefit-Cost Ratio	1.00										

Notes

I. Introduction

1. The World Bank, *Toward Sustained Development in Sub-Saharan Africa*, A Joint Program of Action. (Washington, D.C.: The World Bank, August 1984), p.57.
2. For a more extensive background discussion, see Christopher Colclough and Stephen McCarthy, *The Political Economy of Botswana*, A Study of Growth and Distribution. (New York: Oxford University Press, 1980).
3. The World Bank, *Botswana Issues and Options in the Energy Sector* (Washington, D.C.: The World Bank and UNDP, September 1984); Energy Planning Associates, in Association with the International Forest Science Consultancy, *A Study of Energy Utilization and Requirements in the Rural Sector of Botswana*, Draft Report, volumes I and 11, prepared for the Overseas Development Administration (ODA). (London: ODA, March 1 985:) .
4. The principal present alternative is by rail from Zimbabwe.
5. See the table of energy equivalents at the beginning of this report.

II. Methodology

1. Standard references include: E.J. Mishan, *Cost-Benefit Analysis*, second edition. (New York: Praeger Publishers, 1976); Arnold C. Harberger, *Project Evaluation*, collected papers. (Chicago: The University of Chicago Press, 1972); Partha Dasqupta, Arnartya Sen, and Stephen Marqlin, *Guidelines for Project Evaluation. (*New York: United Nations Publications, 1972); John R. Hansen, *Guide to Practical Project Appraisal. Social Benefit-Cost Analysis in Developing Countries.* (New York: United Nations Publications for UNIDO, 1978); SEMA and .M.D. Little, *Manual of Industrial Project Analysis in Developing Countries*, revised edition. (Paris: OECD,1972); and Lyn Squire and Herman G. van der Talk, *Economic Analyzing of Projects*. (Washington, Q.C.: The World Bank (1975).
2. It should be noted that the undiscounted benefits stream, unlike that of a purely financial asset, does not require uniformity in each time period.
3. Although there appears to be little use of continuous time techniques in project evaluation in either the literature cited in reference one or among government ministries in Bostwana, a proposal for using this technique was made by the former director of the Botswana Technology Centre, Mr. Derek Medford. For references, see: N.B. Davidson, "Method for Economic Assessment of Water Lifting Devices, in "A Survey of the Requirements for an Assessment of Water

Pumping Systems in Botswana," and "Minutes of the meeting of the dialogue group of water lifting devices held on 28-3-84,", Botswana Technology Centre.

4. A useful discussion of some of the techniques used to resolve the problem of polynomial ambiguity is found in Anthony F. Herbst, *Capital Budgeting, Theory, Quantitative Methods, and Applications*. (New York: Harper and Row, 1982), especially chapters 10 and 11.
5. See Thomas A. Goldman, editor, *Cost-Effectiveness Analysis*. (New York: Frederick R. Praeger, Publishers, for the Washington Operations Research Council, 1971/1967); Anthony B. Athinson, *Lectures on Public Economics*. (New York: McGraw-Hill, 1980).

6 The standard method for such amortization is straight-line depreciation although even here the problem of intertemporal bias is not eliminated. For a critique of such methods, see Anthony B. Herbst, *Capital Budgeting Theory*, Quantitative Methods, and Applications. (New York: Harper and Row Publishers, 1982), chapter five.

7. A clear derivation of the optimal inventory model is presented in William J. Baumol, *Economic Theory and Operations Analysis*, fourth edition. (Englewood Cliffs, New Jersey: Prentice-Hall, 1977), pp. 5-11. Baumol's exposition is designed to develop a total inventory cost minimizing solution, which has been modified here to incorporate the cost minimizing inventory cost into the annualized production plus storage unit cost solution. Baurnol's model is based on the initial specification of total inventory cost components, which include the carrying and the reorder cost, and is defined as:

$$\text{a.}\quad C = \frac{KD}{2} + \frac{AQ}{D} + BQ,$$

where: C= Total inventory cost,
K = Per Unit Annual Storage Cost
A = Fixed Storage Cost
Q = Quantity of Output per time period (i.e. per year)
D = Quantity of output Stored
B = Per Unit Storage Transfer Cost

The next step is to calculate the value of D that minimizes total inventory cost. This is done by taking the partial derivative of C with respect to D, setting the derivative equal to zero and solving for D, i.e.:

$$\frac{\delta C}{\delta D} = \frac{K}{2} - \frac{AQ}{D^2} = 0,$$

which reduces the value of D to

$$D = \sqrt{\frac{2AQ}{K}}$$

Squaring both sides and solving for K yields the optimal value of K used in equation nine.

III. **BRET Stoves**

1. The basis for this calculation was an estimate of fuelwood price changes made by D.L. Kgathi, aspects of Firewood Trade Between Rural Kweneng and Urban Gaborone (Botswana: Q Socio--Economic, Perspective," (Gaborone: National Institute of Development Research and Documentation, February 1984), Working Paper No. 46, p. 82, in which the current Pula change in the per 1 axle donkey cart price of fuelwood increased by sixty percent between 1980 and 1983, from 15 to 24 Pula. As this represented a seventeen percent annual rate of increase in the current Pula price, while the rate of consumer prices during that period increased by approximately ten percent per year, a five percent annual rate of increase in the real price of fueIwood was used in the initial analysis.

IV. **BRET Retained Heat Cookers**

1. As pointed out in part 1, although fuelwood accounts for over ninety percent of residential energy consumption, some weight had to be given to non-fuelwood cooking energy, based on the conversion units listed in the beginning of the report.

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Alphabetical List of Individuals Contacted in Botswana

A. **Botswana Renewable Energy Technology Project (BRET)**
Beth Hamilton, ARD Project Consultant
Blair Hamilton, ARD Architect
Jonathan Hodgkin, ARD Engineer
Baintlafatsi Leteemane, Village Technician
Gabaipone Masire, Technical Coordinator
Richard McGowan, ARD Engineer
Moemedi Moswete, Gaborone Facilitator
Modise Motshoge, Wind/Water Technician
Baikanne Mphoyakgosi, Shoshong Facilitator
Mbulawa Mugabe, Extension Coordinator
Judith A. Oki, Extension Support Supervisor
Bruce Pierson, Peace Corps Village Technician
James Sentle, Solar Technician
Jack Shields, ARD Field Supervisor
Ross Tebele, Administrative Coordinator
Carl P. Zietlow, Project Coordinator

B. **Botswana Technology Centre**
T. Aarsse, Director
Nikki Davidson, BTIS Engineer/'Economist

C. **Ministry of Finance and Development Planning**
Merga Afete, Chief Economic Planning Officer
Martin Ngidi, Economist
John Wilson, Economist

D. **Ministry of Mineral Resources and Water**
John Diphaha, Deputy Permanent Secretary
P.H.L. Hugqins, Chief Electrical Engineer
William Kingsmill, Economist
F.O. Motlhatlhedi, Senior Energy Officer
Gunter Rosenber, Energy Advisor
Habalikwe Toholong, Economist

E. **National Development Bank**
A. B.T. Kgosidintsi, Commercial/Industrial Manager

F. **U.S. AID/Botswana**
Stafford Baker, Project Officer
Paul Guedet, Mission Director
Keith Openshaw, Director, Energy Initiatives for Africa