PD-AAH-972 388-0045.7

UNITED STATES OF AMERICA 388004507490

AGENCY FOR INTERNATIONAL DEVELOPMENT

Dacca, Bangladesh

(1)

June 22, 1981

Mr. Ian McCabe
Representative/Bangladesh
The Asia Foundation
55, Road 6A
Dhanmondi, R.A.
Dacca - 9

Subject : Grant No. 388-0045-07

Dear Mr. McCabe:

Persuant to the authority contained in the Foreign Assistance Act of 1961, as amended, the Agency for International Development (hereinafter referred to as "A.I.D." or "Grantor") hereby grants to the Asia Foundation (hereinafter referred to as "TAF" or "Grantee") the sum of $477,709 to provide support for the Energy from Rice Husks project as more fully described in the attachment to this Grant entitled "Program Description." This covers funding for Phase I. AID also grants to TAF $70,000 for partial Phase II project implementation costs, but the disbursement of such funds is conditional on a positive Phase I evaluation. Such an evaluation is now scheduled for July 1982. If at that time A.I.D. determines that the project should proceed to the next phase, the $70,000 can be disbursed and subsequent funding will be arranged, subject to the availability of funds.

This Grant is effective as of the date of this letter and shall apply to commitments made by the Grantee in furtherance of program objectives during the period on or about June 23, 1981 through June 22, 1982.

This Grant is made to the Grantee on condition that the funds will be administered in accordance with the terms and conditions as set forth in Attachment A entitled "Program Description," and Attachment B entitled "Standard Provisions," which have been agreed to by your organization.

Please sign the Statement of Assurance of Compliance, enclosed herein, and the original and seven (7) copies of this letter to acknowledge your acceptance of the conditions under which these funds have been granted.

Please return original and six (6) copies of this Grant.

Sincerely,

Larry K. Crandall
Acting Director

Attachments:

1. Program Description
2. Standard Provisions
3. Statement of Assurance of Compliance

ACCEPTED :

THE ASIA FOUNDATION

BY : JAN WECKE

TITLE : Representative

DATE : June 22, 1981

FISCAL DATA

FUNDS ARE AVAILABLE FROM
APPROPRIATION NO. 72-1111021.3 AND
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TOTAL GRANT AMOUNT : $547,709

Attachment A

3880045074901

PROGRAM DESCRIPTION
BANGLADESH

ENERGY FROM RICE HUSKS, 1981-1984
(TAF/Rice: 388-0045-07)

June 1981

Energy from Rice Husks
(TAF/Rice: 388-0045-07)

CONTENTS

		Page
I.	INTRODUCTION	1
II.	PROJECT SUMMARY	2
III.	PROJECT DESCRIPTION	3
	A. Background and Justification	3
	1. Rice Processing in Bangladesh	3
	2. Economic Importance of Alternative Energy Technologies	4
	3. The Stirling Engine (Technical Feasibility)	6-14
	4. Technical Design Objectives	9
	a. Compatibility of Stirling Unit with Rice Milling Systems	9
	b. Comparative Production Costs	13
	c. Design Rights	14
	5. The Impact of Rice Milling Technologies on Employment	14
	B. Project Design	15
	1. Purpose	15
	2. Assumptions	16
	3. Phases, Activities and Outputs	16
	4. Administration	20
IV.	FINANCIAL PLAN	27
V.	IMPLEMENTATION PLAN	42
VI.	REPORTS AND EVALUATION	51
VII.	STANDARD PROVISIONS	52

ANNEXES

A. "Stirling Engine as a Power Source for Developing Countries"
B. "Rice Hulls as a Source of Power for Small Rice Mills in Bangladesh"
C. USAID Director Project Approval

BEST AVAILABLE DOCUMENT

List of Tables

I. Stirling Engine Energy Flow Figure

II. Evaluation Criteria for Phases I-III

III. Budget Summary

IV. Detailed Budget

V. Implementation Plan

BEST AVAILABLE DOCUMENT

ENERGY FROM RICE HUSKS
(TAF/Rice)

I. INTRODUCTION

In some respects this project has its genesis in a Task Force on Rice Processing and By-Product Utilization, which was constituted by the Bangladesh Government in October 1977. Among the three objectives of the Task Force was the identification of different technologies for rice processing that might be suitable to be adopted in Bangladesh. The Task Force study was coordinated by the Bangladesh Agricultural Research Council., carried out over six weeks in January-February, 1978 by seven Bangladesh Government members and five FAO consultants, and jointly financed by the Ministry of Agriculture and the United Nations Development Programme. Two of the participants in the 1978 Task Force have contributed to the development and design of this project. One of these, L. Merrick Lockwood, was a consultant with USAID/Bangladesh at that time working with BARC.

One major rice processing problem identified by the Task Force was the inefficiency of rice milling techniques, especially as regards the inability to use the by-products effectively. The Task Force recommended the development of various technological improvements in milling, including the selection, whenever possible, of a prime mover using locally available, renewable energy sources.* The project addresses the inefficiency of by-product utilization and the availability of energy by proposing the use of rice husks, an indigenous fuel source as well as by-product of milling, as the energy fuel to operate small rice mills. Specifically, rice husks are proposed to be linked with Stirling Engine Technology through the development of a Stirling system suitable for production and milling use in Bangladesh.

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* Prime Mover: A machine producing work from a high temperature energy source, and rejecting heat at a low temperature.

Ministry of Agriculture, Bangladesh Government, Report of the Task Force on Rice Processing and By-Product Utilization Bangladesh, Dacca, March 1978, p. XI.

Prior to the introduction of electric motors and internal combustion engines powered by cheap fossil fuels, Stirling engines were used as small-scale power sources, particularly for water pumping and room fans. Because of design and metallurgical limitations of that time, the Stirling engine was limited in its power to weight ratio and fuel efficiency. Recently, with the availability of modern materials, Stirling engines have been constructed in configurations which prove its ability to compete with other prime movers such as internal combustion engines, steam engines, and gas turbines.

Small-scale rice milling offers a particularly advantageous circumstance in which to apply Stirling engine technology of the type proposed in this document. At present the rice milling sector is in a state of transition as machine milling is being introduced and small entrepreneurs are looking for equipment to set up small mills in rural areas. The most important advantage, however, is that rice husks, a by-product of the milling process can immediately be put to use as a fuel without problems in transportation or storage.

The types of facilities that would be required to produce the proposed Stirling engine design on a commercial scale already exist in workshops throughout Bangladesh. These include foundry facilities and standard machine shop facilities. Production would generally not require anything more sophisticated than equipment readily available in country.

This means that upon the successful completion of the project the Stirling engine units could be produced in a large number of existing facilities. This could allow for rapid response to market demand and the subsequent competition between workshops should insure the lowest realistic market price for the units.

II. PROJECT SUMMARY

This project introduces to Bangladesh a locally-manufactured engine for agricultural applications which uses a renewable bio-mass fuel source that is available throughout the country. It is basically a research and development project in the non-conventional energy sector.

The project will develop a "Stirling" external combustion heat engine for village-level rice milling utilizing rice husk as its only fuel source. The final product of the project will be an alternative solution to the problem of increasing conventional energy costs and the search for appropriate equipment for small entrepreneurs using mills in rural areas. The Stirling power unit will be a technologically advanced system yet mechanically simple and suitable for construction within workshops in Banglasesh.

Project implementation is divided into three phases over three years. In each phase the critical activities relate to the design, production and testing of the Stirling power unit; as a prototype (phase 1), as four intermediary units (phase 2), and as four pre-production units (Phase 3). In addition, phases one and two have ancillary activities concerned with a study of the availability and utilization of rice husks and the compatibility of alternative milling systems alternatives with the Stirling power units. Each phase of the project is designed to meet certain technical criteria. If, at the end of a phase, the outputs of that phase do not meet the criteria for proceeding to the next phase, the project will be terminated.

The design details and test results will be published and made available to those interested in manufacturing and marketing the Stirling power unit. Recommendations will be made regarding follow-up activities for assistance to manufacturers and distributors.

III. PROJECT DESCRIPTION

A. BACKGROUND AND JUSTIFICATION

1. Rice Processing in Bangladesh

Bangladesh produces an estimated 13 million metric tons of paddy each year making rice its most important agricultural product. Before rice can be eaten, however, appropriate post-harvest processing is required which involves partial boiling (parboiling), drying, milling and separation of by-products. Milling involves "hulling" to remove the outer rice husk and "polishing" the kernel to remove the germ and all or part of the bran layers. By-products from the milling process have their own value as well. Rice bran and germ are excellent feed ingredients for cattle, poultry, fish, and other livestock. Edible oil can be extracted from rice bran given sufficient quality and quantity of bran.

Rice husks, while low in nutritive value, represent a readily available and substantial energy source that is often under-exploited or not used at all. The rice husk winnowed from the grain each year in Bangladesh is roughly equivalent to 300 million U.S. gallons of diesel fuel or ten billion kilowatt hours of electricity in available heat energy (Annex B).

Rice is grown and consumed in nearly all parts of Bangladesh with approximately 80 percent processed and consumed in rural areas.* Commonly the entire process of parboiling, drying, hulling and polishing is carried out in the household, but, increasingly, the hulling and polishing is done in small custom mills.

Rice consumed in urban areas is processed in commercial mills which carry out the entire process of parboiling and milling. These mills operate at capacities ranging from a fraction of a ton per hour to two tons per hour or more.

2. Economic Importance of Alternative Energy Technologies

With the continuing increase in the prices of petroleum products and the consequent increase in energy costs, a strong argument for greater exploitation of the energy available from unconventional sources such as rice husks can be made. In fact, this position is being argued by the Bangladesh Government, the Agency for International Development (AID), and the United Nations Food and Agricultural Organization (FAO).

The Bangladesh Government has placed high priority on seeking ways to encourage maximum utilization of indigenous energy resources thus reducing its present dependence on imported fuel. The contemplated establishment of a new Energy Fuel Institute is a reflection of this priority. Modern rice processing, specifically, has been given preferential status in the Government's Industrial Investment Schedule. Improved rice milling practices are already being encouraged. Applicants for loans for establishing new rice mills must now submit plans incorporating improved rice milling systems before their request can be considered by the various commercial investment institutions.

On August 3, 1977, Congress amended the Foreign Assist- Act by adding a section entitled Renewable and Unconventional Energy Technologies. Proposing:

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* Report of the Task Force on Rice Processing and By-product Utilization in Bangladesh, Ministry of Agriculture, Government of the People's Republic of Bangladesh, March 1978.

> "... cooperative programs with developing countries in energy production and conservation, with particular emphasis on programs in research, development, and use of small-scale, decentralized, renewable energy sources in rural areas... directed toward the earliest practicable development and use of energy technologies which are environmentally acceptable to and affordable by the people using them, are simple and inexpensive to use and maintain, and are transferable from one region of the world to another."

The USAID/Dacca energy strategy, as stated in the FY 1983 CDSS*, notes: "The development of energy resources for the rural areas is critical to growth in agriculture and industry. Higher rates of energy consumption are required to operate irrigation pumps, rice mills, and small factories. To the extent possible, these requirements should be met with indigenous resources." (p. 56) This project helps to address this Mission concern by developing an alternative, non-conventional indigenous energy resource as the fuel for motive power for small rural rice mills. It also provides the opportunity for extending the technology developed by the project to other uses, such as irrigation pumps. This potential will be examined in the final project report. However, the most pertinent aspect of the project, as it concerns the Mission energy strategy, is that the constraints of energy, in at least rice milling, may be alleviated to a considerable extent through the product development proposed by this project.

A recently published Agricultural Service Bulletin of the United Nations Food and Agricultural Organization (FAO) on energy from rice husk states:

> "Need now exists of an alternative type of small prime mover which can be operated using such fuels as low-grade coal, lignite, wood, and agricultural and industrial wastes. The need for such a small engine is most acute in countries with few or no indigenous resources of liquid fuel and where mechanization of

* Country Development Strategy Statement.

> agriculture as well as village industries is one way of raising standards of living. When a rice mill is operated from a power-grid, it must be considered that either foreign exchange or a national resource is being utilized."*

The economic benefit to the country from the project will be foreign exchange savings resulting from the use of an indigenous fuel source. This economic benefit should also increase over time assuming petroleum costs will rise in real terms. While Bangladesh has natural gas which could be used as a fuel source for rice processing, there is an opportunity cost associated with its use and this can also be expected to increase over time in real terms. In summary, there is significant economic justification for developing the technology proposed in this project.

3. The Stirling Engine

This project proposes to develop a Stirling engine fueled by rice husks to provide the suitable motive power for small rural rice mills in Bangladesh. There are several reasons why the Stirling engine has been selected for development with rice milling.

First, the engine is an external combustion engine. As such it has several attractive technical advantages:

-- the Stirling engine can use any heat source to generate power. Early engines were commonly operated on coal, wood, charcoal, or kerosene. The Stirling engine is also suited for operation with solar energy or energy from agricultural wastes.

-- with an external combustion system it is possible to design furnaces that give high fuel efficiencies with a minimum of pollutants.

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* Beagle, Eldon C. Rice Husk Conversion to Energy, Agricultural Service Bulletin 31, Rome: F.A.O., 1978

-- there is no mixing of corrosive gases with the working gas because heat is transferred through the cylinder head to the working medium inside. Consequently, there is no chemical breakdown of lubricants as there is with internal combustion engines and wearing parts have a longer working life.

-- Stirling engines can be designed so that there are no wearing surfaces or seals in the hot part of the engine. With the piston seal in the cool part of the engine it is possible to use simple and durable sealing systems, such as greased leather. Such machines have operated for decades with no more than occasional greasing and replacement of the leather seal (See Annex A).

-- Stirling engine has no complex and precisely made valves, fuel injectors, carburetion equipment or ignition equipment. This eliminates the first cost, replacement cost, and the skilled maintenance required for such components. The Stirling engine can be disassembled, repaired and reassembled with tools similar to those available to a bicycle mechanic.

Second, the Stirling engine's historical disadvantages have recently been either overcome or become less significant. In the early 1800's steam engines were the cause of frequent and often fatal accidents. These accidents, usually boiler explosions, were the inevitable result of working with a high pressure and temperature medium, such as steam, when materials, manufacturing methods and legislation had not evolved to the point where safety could be ensured. In 1816, the Reverend Robert Stirling, a Scottish clergyman, was granted a patent for his design of a heat engine using air as the working medium. The engine, named after him, eliminated the boiler and used heat from the furnace to heat air, contained in a cylinder, which then expanded against a piston connected to a crankshaft -- an external combustion engine. Although the Stirling engine at that time offered a safer and more efficient alternative to the existing steam engines, it also had some distinct disadvantages:

a. Because of limitations in design capabilities and construction materials of the time, the early Stirling engines were frequently not fuel efficient.

b. The Stirling engine is bulky and heavy by comparison with the internal combustion engines.

By the beginning of this century the Stirling engine was largely displaced by internal combustion engines and electric motors.

Since then a number of innovations in design capabilities and construction materials have been made which reduces the previous disadvantages in this area. Modern developments in Stirling engine technology have concentrated on sophisticated uses, most notably the automobile engine, as well as aerospace and military applications. U.S. Government investments on the Stirling engine have been mostly for aerospace and automotive uses in the United States. (See Annex A, Table I, p. 5 for information on recent work in Stirling engines.) However, the result of most modern applications has been a proliferation of very sophisticated and efficient designs but at the cost of requiring sophisticated materials, exotic working gases (helium or hydrogen) and high working temperatures and pressures. Simplicity, ease of manufacture and maintenance, and low cost have been sacrificed.

The issue of the bulk and weight of a Stirling engine becomes more acceptable if one considers that a Stirling engine fueled by raw unrefined fuels such as rice husk, wood, charcoal, or even coal is equivalent to an internal combustion engine with its own built-in refinery.

Third, preliminary investigations indicate the Stirling engine can be modified and adapted to mechanically simple manufacturing capabilities. This is due to the work presently carried out by Sunpower, Incorporated, of Athens, Ohio, which has focused on Stirling engine designs especially for Third World use. Sunpower has developed a design methodology for Stirling engines which allows the optimization of a multitude of factors affecting Stirling engine operation such as fluid flow, heat transfer and the dimensions of critical components of the engine. By using a computer-based design procedure, Sunpower has, for example, taken a 1900's hot air engine which originally produced 40 watts (1/20 hp) and, by optimizing the design, obtained 800 watts (over 1 hp) with a machine nearly the same size (See Annex A).

In October 1979, as a preliminary step in the development of this proposal, the Asia Foundation brought Mr. William T. Beale of Sunpower, Inc. to Bangladesh to participate in a study of the possibility for Stirling engine technology to meet some of the power needs of Third World countries. After extensive visits to different workshops in Dacca and Calcutta, the conclusions of the feasibility study were that simple Stirling engines could find effective applications in Bangladesh and that such engines could be locally manufactured, utilizing components or materials that are readily available (See Annex A).

4. Technical Design Objectives

a. Compatability of Stirling Unit with Milling Systems

Small rural custom rice mills operating in Bangladesh typically use steel hullers. The steel huller has been criticized as wasteful and inefficient and it is true that when used for milling raw rice it produces a higher percentage of broken kernals. However, when milling parboiled rice these steel hullers prove to be more efficient. No other milling system has yet successfully competed with the steel huller's low initial cost, ease of operation and ease of maintenance. Therefore, any power system under consideration for small custom mills should be designed to cope with the power requirements of steel hullers.

Three sizes of steel rice hullers are currently marketed in Bangladesh:

Huller	Capacity	Power Required
No. 2	2/3 TPH	20-30 hp
No. 8	1/2 TPH	15-20 hp
No. 4	1/5 TPH	5-15 hp

Development of the Stirling engine for the smallest huller is proposed in this project. A Stirling engine-powered No. 4 huller would give a competitive edge to the smallest rural custom rice mills which require power in the range of 5 hp,

as compared to the larger No. 2 huller which requires 20 hp or more. A Stirling unit of 5 hp could also be used for a number of other agricultural operations, particularly irrigation or grain drying.

The selection of engine power must ultimately depend upon a more detailed study of power requirements for rice milling. Such a study has been incorporated into this project. The following calculations assume a power requirement of 5 hp as typical of small custom rice mills which presently use 5 hp diesel engines to drive their hullers.

One horsepower is equivalent to 2,547 BTU/hr, thus a 5 hp engine operating for one hour will produce at its shaft:

$$5 \text{ hp} \times \frac{2{,}547 \text{ BTU/hr}}{\text{hp}} = 12{,}735 \text{ BTU/hr}$$

Assuming an engine/furnace efficiency of 5 percent, the unit will consume energy at a rate of 254,700 BTU/hr.

A No. 4 huller milling 1/5 ton of paddy each hour will yield about 80 pounds of rice husks per hour (husks comprise 20 percent of the weight of paddy). The heat value of husks when burned is, 6000 BTU/lb so that the energy available from the husks is, 80 lb/hr X 6000 BTU/lb = 480,000 BTU/hr of heat.

The 254,700 BTU/hr required by the Stirling engine to operate the rice mill amounts to about one-half of the available 480,000 BTU/hr. This means that the Stirling engine will use only one-half of the husks to do the milling and the remaining one-half of the rice husks can be used for traditional uses such as parboiling , or for other power requirements such as running irrigation pumps. Excess husks from operating such a mill for one eight-hour day would power a 5 hp Stirling engine-operated water pump for an equivalent eight hour day. If the overall efficiency of the Stirling engine/furnace combination is less than the estimated 5 percent some of the otherwise excess husk would be used to make up the deficit.

An alternative way in which the efficiency of the Stirling unit as part of the total milling system could be increased dramatically would be to use the rejected heat from the furnace

and engine cooling system for purposes of drying or parboiling. Table I, taken from Graham Walker's book on Stirling engines, illustrates diagramatically the large amount of heat rejected in a Stirling power system. This case represents the heat flow in a fairly efficient Stirling engine which converts 32% of the heat to work. In this figure 46% of the heat is carried away in the cooling water and 14% is carried away with the exhaust. This energy, a total of 60% of the heat input, can be harnessed for parboiling or drying operations. The Stirling system to be developed in this project will be of simple design with lower efficiency, estimated to be about 5%, so that even more than 60% of the heat input would be available for other operations.

If efficiency considerations demand it, a decision could be made at a time in the evaluation to incorporate drying and/or parboiling functions. Sunpower has confirmed that they can develop such modifications in the design. Determination of the utilization of waste heat for ancillary functions shall be made with a view towards balancing the effect of such an activity in reducing employment opportunities for women. Further decisions will be made on the use of this waste heat once an assessment of husk utilization has been finalized.

Another consideration for selecting a small size huller to be driven by the Stirling power unit relates to the objective of devising and economically competitive unit. A breakdown of milling charges an costs per maund (82 lbs), as reported by a number of small custom rice mills using electrically driven No. 2 hullers, gives an idea of energy, spare parts and labor costs.

Charge to customer ...	...	Tk. 3.00
Wage of operator ...	Tk. 0.50	
Cost of spare parts ...	Tk. 0.50	
Electricity charges ...	Tk. 0.60	
Other costs and profits...	Tk. 1.40	
Total =	Tk. 3.00	Tk. 3.00

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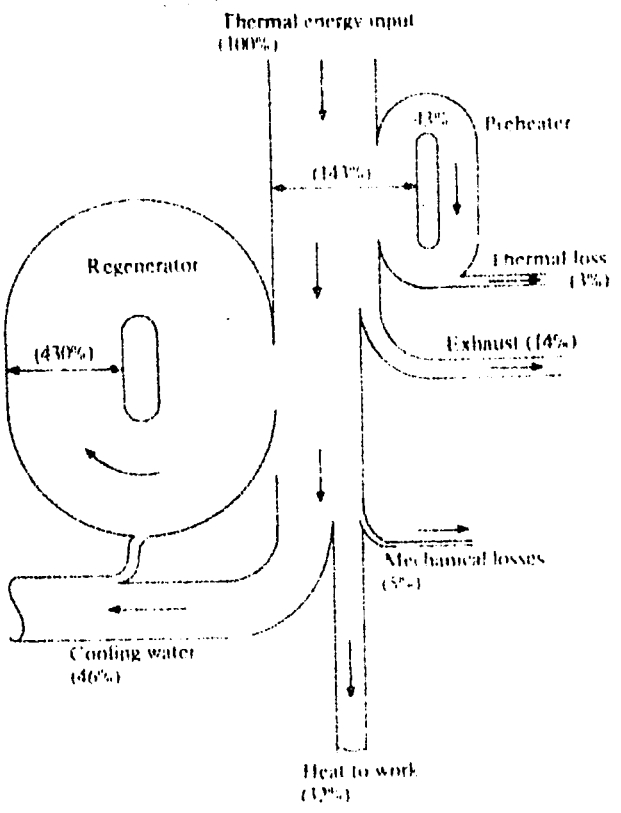

Table I - Energy flow in a Stirling engine

Source : Graham Walker, Stirling Engines, Clarendon Press, Oxford, 1980

Small mills in rural areas may process as little as 100 maunds of paddy per week while those in areas with more active trade may process some 400 maunds or more per week. For the smaller capacity mill, the application of Stirling engine could result in an annual savings in energy costs of Tk. 0.60/md X 5,000 mds = Tk. 3.000 ($200), assuming 50 weeks of milling operations. For the mill with a 400 maunds per week capacity savings could be four times as much or Tk. 12,000 ($800). Rural mills also grinding wheat use the same power source as those for milling rice but at different times. Stirling engines could be used for wheat grinding as well with the consequent power cost savings.

b. Comparative Production Costs

There are several reasons why a Stirling engine of the type proposed is envisioned to be produced at a cost competitive with that of an internal combustion engine. The Stirling engine does not require any valves, fuel injectors, carburetors or ignition equipment. This reduces cost and brings the manufacturing technology within the reach of smaller workshops where overhead costs are low and competition would keep market prices at a minimum. Taking these factors into consideration it is expected that the Stirling unit will be produced in Bangladesh at a cost which will be less than that of steam or internal combustion engines of equivalent power. At present, the manufacturing cost comparisons for 5 horsepower engines are estimated to be:

- steam = 30-35 hp is the smallest size commercially available. Without the boiler, cost is about $2000
- diesel = $480 - 720
- electric = $470 - 588
- stirling = $300 - 600

The Stirling production cost has been estimated by Sunpower. The above costs will be reviewed at the end of each phase to ensure the Stirling unit will successfully compete with its equivalent engine competitors.

c. Design Rights

It is not intended through this project to invent a new type of engine. Rather, it is believed that the energy available in rice husks can be harnessed to operate small rural rice mills by incorporating a technology which was widely used at the turn of the century and which was displaced by the advent of cheap petroleum based energy. While the concept of the Stirling engine is an old one, the success of this project depends upon the skillful design of the various engine components to produce a machine of acceptable size and cost, suitable for local manufacture in Third World countries. Because design parameters and not new ideas are involved the results of this project will not be patentable under United States patent laws. Therefore, a final technical design objective is to develop a commercially competitive but inexpensive item, designed for small local manafacturing and easily replicable. In this way the beneficiaries of the developed technology will be ultimately small entrepreneurs and consumers of milling services.

5. The Impact of Rice Milling Technologies on Employment

The steel huller can mill in a matter of minutes a quantity of rice that would take a woman a full working day to husk and polish manually on a "dheki." This efficiency along with the low cost of the milling service has resulted in the rapid proliferation of steel hullers as soon as electricity has become available in rural areas. This shift from manual methods to machine processing of rice often has an adverse impact on women who depend upon rice processing for livelihood, though they are still called on to do the parboiling and drying as these functions are not performed at rural custom rice mills. There are instances where through the activities of women's cooperatives, individual women have been able to obtain credit to purchase paddy, process it and market the rice. In these cases the women themselves have made use of the local rice mills to carry out the husking which is the most laborious and time consuming part of the operation. In this way they are able to process more rice and consequently earn more money in a given period. A limiting factor in the use of rice mills by women participating in the processing and marketing of rice is the distance of the mill from their house. If the mill is too far away, the difficulty and cost of transportation outweighs the economic advantage of using the mill.

It will be appreciated that from the point-of-view of maximizing income distribution and encouraging the continued involvement of women in the rice processing sector it would be better to have many small rice mills rather than fewer large ones. The investment cost of the mill would be lower, bringing the opportunity of owning and operating a mill within the reach of smaller entrepreneurs and would in fact discourage those with more to invest as smaller mills would require more person/hours for a given quantity of rice milled. Secondly, with more small mills the average house-to-mill distance would decrease and more households would be within the distance where it becomes economically feasible to incorporate machine milling with household parboiling and drying.

While the most obvious benefit of this project is to develop an alternative power source, which uses indigenous fuel, for small rice mills in rural areas, it should be realized that the introduction of this technology may offer a unique opportunity to guide the direction of the rural rice processing sector in the favor of small entrepreneurs and women. This is because the size of rice husk-fueled Stirling engines will dictate the maximum size of a milling machine that can be used. It is expected that this may be of about 5 horsepower which means that it would have to be used with the smallest of the available steel hullers. In the end, the most profound impact of this technology may be the direction that it gives to the rural rice processing sector and the potential benefit to women and to small investors. For this reason, close contact will be maintained with groups such as the Integrated Rural Development Program and the Bangladesh Rural Advancement Committee who are actively involved in the development of women's groups in rural Bangladesh and with their cooperation it may be possible to insure the maximum benefit from this project for the continued involvement of women in the rice processing sector.

B. PROJECT DESIGN

1. Purpose

The purpose of this project is to design, develop and test a rice husk-fueled stirling power system for providing motive

power for small rural rice mills in Bangladesh.

2. Assumptions

The project is based on a series of hypotheses of which the following are the most critical:

a. that alternative energy resources are needed due to the high cost of petroleum-based fuels;

b. that rice milling is an important area where the constraints of energy costs are critical -- the Stirling engine provides the opportunity for developing an alternative, non-conventional energy resource;

c. that this possible alternative energy resource is rice-husks as they are a by-product of milling and hence readily available;

d. that the Stirling engine is a suitable engine powered by rice husk-fuel for milling;

e. that there will be a high demand for the final product because of its combined technical and economic advantages : fuel availability, engine efficiency, and local workshop manufacturing capability.

3. Phases, Activities and Outputs

The project consists of a three phase, three year, program for developing a Stirling power unit. Each phase, comprising approximately twelve months of activities, is designed so that a later phase is canceled if the preceding one is unsuccessful. Criteria have been developed against which outputs of each phase can be reviewed and evaluated. Table II on page 16a summarizes project phases, activities and their respective criteria. The criteria will be reviewed and perhaps modified by the technical evaluators during their project organizational meetings.

TABLE II

TAF/RICE

ACTIVITIES AND EVALUATION CRITERIA FOR PHASES I-III

ase I -12 mos.)	Task/Activities	GO/NO-GO Criteria
	A. Development and production of a Striling Power Unit proto-type at Sunpower, Inc. Athens, Ohio. B. Ongoing assessment of rice husk availability, its economic value and its utilization.	A. Stirling Power Unit Proto-type: 1. The engine works efficiently with rice husks as the fuel. 2. The engine produces the specified power necessary for operating a small rural rice mill (No. 4 huller 3. The design is deemed feasible for extant Bangladesh manufacturing capability in terms of the processes and manufacturing technologies involved. 4. The production cost is reasonable and competitive with fossil-based fuel engines in Bangladesh. B. Projections can be established for husk availability and value for commercial production of the engine.
ase II 3-24 mos.)	A. Fabrication and testing of four intermediate Stirling Power Units at Kumudini Welfare Trust in Bangladesh. B. Determination of future Stirling Power Unit applicability in alternative milling systems.	A. The Intermediate Stirling Power Units: 1. Are locally manufacturable, provide cost estimates for pre-production models, and are operable under field conditions. 2. Comparative advantages in terms of real energy costs are maintained. B. Stirling Power Units are shown to be compatible with milling systems.
ase III -36 mos.)	A. Designing manufacturing patterns for mass-production (jigs and fittings) B. Production of four pre-production units by existing local manufacturers (under sub-contract). C. Evaluation (testing) of pre-production units. D. Preparation of Final Report: Design details and test results.	A-C. Production Techniques are developed and are operable. D. Manual for producing Stirling Power Units on mass-scale by standard local manufacturers.

In phase one, Sunpower, Inc. will design and build the prototype in the United States intended for manufacture in Bangladesh. During this period additional information will be collected to determine the availability and alternative utilization of rice husk. This activity is essential to confirm the availability of rice husk to fuel the Stirling power unit. At this time the design to determine the adaption of the new power unit with existing milling equipment will also be undertaken. The second phase of the project will result in four Stirling engine intermediate models manufactured in Bangladesh by the Kumudini Welfare Trust. The models will be extensively field tested. Phase two will also result in the determination of the Stirling unit's applicability to alternative milling systems. In phase three, four pre-production models will be developed and made operable. A brief description of these phases follows below.

a. Phase One

(1) Prototype Design and Production

At the beginning of the project an engineer from Sunpower will work in Bangladesh for approximately one month to determine the optimum power requirements for the Stirling engine and furnace for use in small village-rice mills. He will also further assess available materials and manufacturing facilities in Bangladesh in order that the prototype design will embody materials and techniques suitable for small scale commercial production in Bangladesh. He will bring with him the necessary equipment to assess the actual power consumption of typical village rice mills in Bangladesh.

The design and manufacture of the initial Stirling engine prototype system will be done at the Sunpower facility in Ohio. Their design and engineering Staff will utilize proven computer-assisted design methods, models, and other advanced technology in the design of the system. There will be continued coordination between the Sunpower engineers and others involved in Bangladesh regarding size, available material, and suitable manufacturing processes. Sunpower will also design the husk-fueled furnace required for the Stirling engine.

Sunpower will manufacture and test the prototype Stirling system with an integrated husk-fueled furnace at their Ohio facility. After successful testing and acceptance by a twelfth month review team the prototype engine and furnace system will be shipped to Bangladesh.

As part of the design development of the Stirling power units project personnel will maintain contact with local workshops to insure that the production methods which are being developed for manufacture of the Stirling unit are in fact compatible with locally available facilities. Certain specialized jobs such as pattern making will be contracted out to local workshops in an effort to test these capabilities early in the project.

(2) Husk Availability and Utilization

Information on present uses of husks will be obtained by spot surveys in representative parts of Bangladesh. An important competing use for rice husks might be as fuel to generate heat for drying parboiled rice at the larger rice mills. The extent to which this demand for rice husk may develop depends largely on the effectiveness of present sun-drying practices and the potential of these methods to meet future needs of the milling sector. An assessment of the possible future need for rice husks in drying will be included in the final report.

(3) Design for Studying Alternative Milling Systems

An important aspect of projected introduction of Stirling technology in small rice mills is the adaption of the new power unit so that it can be used to operate existing milling equipment, thus capitalizing on the existance of an established supply of machinery and spare parts. It is recognized, however, that there are advantages to improved rice milling techniques both for the operation of the Stirling engine (improved fuel characteristics of the husk) as well as the potential for reduced food losses and improved quality of the by-products. For this reason this project will include an evaluation of alternative and improved milling

techniques that could be used with the Stirling power unit. The design and support materials for this evaluation will be prepared and obtained during Phase One.

b. Phase Two

(1) Intermediate Models

Four intermediate models will be constructed in the Kumudini Welfare Trust workshops embodying experience gained during the testing of the prototype. The four intermediate model units will then be placed in operation at selected village rice mills in rural Bangladesh for field trials.

The Stirling engine power unit will be designed so that even for commercial production only basic machine tools and fabricating equipment will be required. these tools and equipment would include a metal lathe, milling machine, drill press, welding equipment and standard hand tools required for fitting work. Foundry facilities are widely available in Bangladesh and good quality castings in ferrous and non-ferrous metals can be easily obtained to order.

(2) Alternative Milling Systems

Evaluation of alternative milling machinery will be conducted at the Kumudini Welfare Trust facilities. Preliminary tests will be carried out on the equipment operated in the conventional manner with electric power. When the Stirling power units become available in the second year of the project the milling equipment will be adapted to operate with a Stirling prime mover and the overall system will be evaluated as to capacity, product quality, and husk consumption.

c. Phase Three

(1) Pre-Production Units

Upon successful completion of the second phase, four pre-production Stirling power units will be manufactured. The activities involved in this phase include : designing manufacturing patterns for mass production, fabricating four

pre-production units under sub-contracts, and testing the pre-production units. With only modest changes the existing Kumudini workshops would be capable of producing 200 units of the Stirling engine power unit per year. This quantity would be sufficient to make an accurate assessment of the market demand fo. these units. If a much higher rate of production is justified it is expected that this would be handled by other commercial workshops within Bangladesh. However, the project will not confine itself to Kumudini's manufacturing capability and will seek to tap all reputable, local manufacturing resources. TAF recognizes this need and will pursue coordination on all manufacturing aspects between Kumudini and other machine shops.

(2) Report Preparation and Dissemination

A report including design and development details and information on testing and manufacturing results will be prepared. The report will completely describe all facets of manufacture, service operation and development extension of the final model deemed suitable for commercial-level manafacture and use in Bangladesh. The report will also include performance data and information on the alternative milling systems that will have been evaluated for use with the Stirling power unit. This information will be prepared in a format suitable for distribution to Bangladeshi and other Third World manufacturers interested in production and distribution of the Stirling power units. In addtition the project staff, the Kumudini Welfare Trust and TAF will work to insure that documentation on the Stirling power unit is presented at conferences and seminars both internationally and in Bangladesh.

(3) Subsequent Commercial Production

In order to determine the potential for subsequent commercial production and distribution of the Stirling power unit the final report will include the following :

(a) A description of equipment needed to produce the Stirling power unit based on the activities in phase 3 of the project.

(b) An assessment of currently available production facilities in Bangladesh in light of the above requirements.

(c) A projection of demand for the Stirling power unit based on field experience.

(d) An assessment as to whether the dissemination of information, which is a component of this project, along with the interest manufacturers have shown by this time is sufficient to insure the spread of this technology or whether further follow-up activities would be needed. Such activities might include technical assistance to workshops interested in producing the Stirling units, assistance in obtaining credit for purchase of machinery or materials, and assistance in marketing.

4. Project Administration

Three institutions will be involved with project implementation: The Asia Foundation, Sunpower, Incorporated and Kumudini Welfare Trust.

a. The Asia Foundation is a publicly - supported and privately-managed non-profit social and economic development organization incorporated in the State of California in 1954. The Foundation's headquarters are located in San Francisco and it maintains Representatives and offices in several Asian countries, including Bangladesh.

With support provided by the Foundation's headquarters in San Francisco, the Foundation manages, monitors, and evaluates all grants made in Bangladesh. The Foundation also conducts the necessary auditing, procurement of goods and services, and contracting required by its program.

The office, with a local Representative, has been maintained in Dacca for nearly 26 years to render grant assistance in many forms in a variety of

program fields. Recent years have seen greater Foundation attention given to the support of in-country programs, usually with local private voluntary groups, to benefit the poorest of the country.

The Foundation has also undertaken the implementation of several special purpose grants on behalf of USAID including a $500,000 grant for family planning and health service which was begun in 1979 and a three-year Parliament Library improvemnnt project also begun in 1979. The Foundation's office in Dacca is staffed with two expatriate Foundation officers and 17 local staff. It retains several specialists on contract to give attention to special purpose projects, such as this project. Contractors will be added as needed.

The Foundation will administer this project using a grantee-contract relationship with Sunpower and a grantee-subgrantee relationship with Kumudini Welfare Trust. In addition,TAF will contract separately project staff and consultants. There will be a Project Supervisor, Administrator and clerical staff based in Dacca. There will be two technical consultants: a specialist in rice husks and furnaces and one in Stirling engines. The San Francisco office will be responsible for all international contractual arrangements; the Dacca office will manage all local project implementation.

b. Sunpower Incorporated is an engineering, research and development company based in Athens, Ohio which designs and builds heat engines with a special emphasis on applications of the free piston Stirling engine. Sunpower has accepted the challenge of designing efficient and durable machinery which will conserve existing fossil fuels and will utilize renewable sources of energy which are environmentally sound, cost-effective

and socially appropriate. Sunpower will design and develop the Stirling power unit and assist in all engine testing, review and evaluation.

In May 1981 USAID/Bangladesh requested AID/Washington to ascertain, upon its behalf, Sunpower's technical performance and reliability. All persons and institutions contacted reported that Sunpower is the pioneer in the development of Stirling engines and that they are favourably impressed with the firm's technical capabilities and adherence to contractual obligations.

Established in 1971 through the initiative of Ohio University professor William Beale, Sunpower has grown at a modest but steady pace, developing a free piston Beale-invented adaptation of the Stirling engine. Hands on engineering experience and proven analytical ability using computer design methods have made Sunpower a leader in Stirling engine development.

While the diminishing supply and rapidly rising cost of conventional fuels has stimulated much research and development on alternative energy power resources, most has been directed toward highly sophisticated uses in the already established technological markets of the developed world. Most of the Stirling engine development undertaken is directed toward the automotive industry and other needs of industrialized societies, Sunpower, on the other hand, has been directing its attention toward the needs of the developing world seeking appropriate applications of its prototype for post-harvest processes, water pumps, electric generators, refrigeration and air conditioning.

The staff at Sunpower reflect engineer, scientific and management competencies. Demonstrated experience in such diverse technical areas as mechanical, electrical, and industrial engineering,

and physics, mathematics and computer science allow for balanced and versatile design teams. Engineers, acting as project managers, direct and coordinate these teams through the simulation, building and testing of Stirling engines in Sunpower's computer shop and laboratory facilities.

Sunpower has designed and built free piston Stirling engines with power outputs ranging from 7 watts to 3.5 kilowatts. They have produced a number of designs for the Jet Propulsion Laboratory, Argonne National Laboratory and NASA. They have built and demonstrated a number of free cylinder solar powered water pumps including the current development of a pump capable of lifting one liter of water from a depth of ten meters in one second. A prototype Stirling engine electric power generator capable of operating fans, television sets, trolling motors and other power equipment has also been developed as an experimental model for eventual application for larger generators with power outputs from 200 to 1000 watts. Sunpower has also demonstrated the feasibility of freon-free cooling systems using Stirling application for remote area refrigeration of vaccines, dairy products and agricultural perishables.

Lastly, Sunpower, as a foundation for its hardware projects, has developed and uses computer programs capable of modelling Stirling cycle machines which provide continual feedback and verification allowing Sunpower to optimize engine designs in accordance with end user performance specifications.

Sunpower is interested in participating in the project as described in this proposal. Their incentive is that this project presents Sunpower with the opportunity to continue to apply their technology to problems in the developing world. With most of the activity for

alternative energy development directed toward the needs of the West supported by millions of dollars in development costs, Sunpower views this project as a special opportunity to apply their technology to the benefit of developing countries and to focus wider attention on the variety of applications to which Stirling power systems could be applied in the developing world.

c. The Kumudini Welfare Trust of Bengal (KWT), founded in 1945 by philanthropist, the late R.P. Shaha, is comprised of three business activities: a riverboat repair yard, a system of river barges and steam tugs, and a jute press mill located in the industrial town of Narayanganj. In addition, a rice mill and a pharmaceutical industry, in design stages, represent planned diversification of Trust business activities making it less dependent on its primary earner -- jute. Earnings from Trust industries are used to support Trust - established benevolent institutions located in Mirzapur and Tangail. The institutions established, operated, and maintained by KWT are; a 750-bed, free hospital rendering health care services to nearly 1,950 inpatients and outpatients each day, a girl's primary and secondary school with 1,000 students, and a college of nursing which trains registered nurses, mid-wives, and female para-medics. In addition, the Trust has established and manages two women's cooperatives, one a hand-loom industry located in Mirzapur, the other a handicraft industry located in an industrial workers housing complex in Narayanganj.

As a trust, KWT enjoys tax-exempt status with the Bangladesh Government and, as the necessity of administering such a complexity of projects dictates, it also benefits from progressive, and efficient management. Quick to recognise the value of many new ideas KWT management seeks opportunities to reduce overhead costs for its

institutions and to adopt new innovations which employ more people, particularly women, benefit Bangladesh and, if possible, create additional revenue for the support of the Trust institutions. Examples of this progressive nature are evident in vegetable farms, paddy cultivation, fish farming, fruit growing, and the planned pharmaceutical factory which will reduce overhead costs for the hospital and educational institutions by providing food and standard drugs. The development and sale of a succesful baby-balance scale, the development of agricultural equipment based on IRRI designs, and the proposed alternate energy project, the subject of this proposal, are further indications of imaginative approaches to income generation.

The Kumudini Welfare Trust is proposed as the Bangladesh implementer of this project for several reasons. The incentive of industrial diversification, employment generation, overhead reduction, technical innovation, and income generation have been noted above. This project also appeals directly to Trust aspirations. In exchange for the opportunity to adopt a new technology, the Trust has offered the use of its machine shops, its machinists, fabrication materials and equipment, some lodging and transportation for visiting technical consultants, management, accounting and clerical services. The new rice mill industry will be designed so that it can accomodate much of the experimentation represented in this proposal. Lastly, and of great importance, is that as a private trust, KWT is not encumbered by many of the bureaucratic impediments confronting government organizations. The Trust has a confident and satisfactory working relationship with The Asia Foundation resulting from a number of project grants made since 1976.

IV. FINANCIAL PLAN

This project is to be funded on a phased basis. Each subsequent phase will be funded by USAID subject to a positive technical evaluation following the criteria outlined in Table II. Should any phase not meet the evaluation criteria, the unspent funds of that phase will be deobligated. The project budget, summary and details, are provided in Tables III and IV. The following section describes and explains certain project costs.

Table III Summary of Budget Costs ($000)

	USAID				KUMUDINI WELFARE TRUST*			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
I. Design Costs	144,000	60,000	36,000	240,000				
II. Facilities	25,000	6,500	5,900	37,400	25,700	23,100	24,600	73,400
III. Personnel	133,135	105,814	99,765	338,714	19,000	22,800	27,360	69,160
IV. Equipment	62,090	6,520	1,440	70,050	15,700	19,270	23,178	58,148
V. References and Publishing Costs	2,200	1,900	3,700	7,800				
Sub-Total	366,425	180,734	146,805	693,964	60,400	65,170	75,138	200,708
VI. TAF Program Management Costs	24,499	19,548	19,548	63,595				
Sub-Total	390,924	200,282	166,353	757,559				
VII. Indirect Costs (22.2%)	86,785	44,463	36,930	168,178				
TOTAL PROJECT COSTS	477,709	244,745	203,283	925,737	60,400	65,170	75,138	200,708

NOTE: The Grantee may not exceed the total amount of the funds obligated against the budget. Adjustments among line items are unrestricted.

* Illustrative

Table IV Detailed Project Budget Costs ($000)

	USAID				KUMUDINI WELFARE TRUST			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
I. DESIGN COSTS (SUNPOWER, INC.)	144,000	60,000	36,000	240,000				
II. FACILITIES								
A. Project Office (includes furnishings and equipment)	8,000	2,400	2,000	12,400	3,500	2,000	2,000	7,500
B. Project Workshop and Storage	2,500	1,100	400	4,000	5,500	3,000	3,000	11,500
C. Rice Processing Facilities					9,000	9,000	9,000	27,000
D. Machineshop					1,500	1,800	2,200	5,500
E. Foundry					1,500	1,600	1,700	4,800
F. Vehicle Purchase and Operation	14,500	3,000	3,500	21,000	2,500	3,000	3,600	9,100
G. Offices/Furnishings					2,000	2,400	2,800	7,200
H. Telephone					200	300	300	800
Sub-Total	25,000	6,500	5,900	37,400	25,700	23,100	24,600	73,400

	USAID				KUMUDINI WELFARE TRUST			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
III. PERSONNEL								
A. International								
1. Project Supervisor								
a. Salary, Fees, Allowances	84,000	55,720	58,321	198,041				
b. Travel (BD-Ohio) x 4 (Return)	11,600			11,600				
c. Per Diem (7x4 = 28 days)	1,260			1,260				
2. Project Administrator								
Salaries, Fees, Allowances	10,000	10,500	11,250	31,750				
3. Sun Power Engineers								
a. Salaries, Fees Allowances (5 months)	2,070	6,210	2,070	10,350				
b. Travel (Ohio-BD) x 5 (Return)	2,900	14,500	8,700	26,100				
c. Per Diem (9x4 = 36 days)		1,242	1,242	2,484				
4. Husk Utilization Consultant								
a. Salaries, Fees, Allowances (3x7 = 21 days) Yr 1 (9x4 = 36 days) Yr 2+3	4,200	3,600	3,600	11,400				
b. Travel (Cal-Oh)x7 (return)Yr 1 Cal-BDx4(return)Yr 2-3	5,320	4,000	4,000	13,320				
c. Per Diem (3x3 = 9 days) Yr 1 (9x4 = 36 days) Yr 2+3)	945	1,242	1,242	3,429				

	USAID				KUMUDINI WELFARE TRUST			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
5. Stirling Engine Consultnnt								
a. Salaries, Fees, Allowances (3x4) = 12 days	2,400			2,400				
b. Travel (Can-Ohio) x 4 (Return)	2,600			2,600				
c. Per Diem (3x4) = 12 days	540			540				
Sub-Total A	127,835	97,014	90,425	315,274				
B. Personnel (TAF/KWT)* Part-time								
Local								
1. Project Engineer (0/1)					5,000	6,000	7,200	18,200
2. Secretary (*1/*1)	1,200	1,440	1,728	4,368	3,000	3,600	4,320	10,920
3. Accountant (0/*1)					1,000	1,200	1,440	3,640
4. Welder (0/*1)					500	600	720	1,820
5. Machinists (1/*6)	1,200	1,440	1,728	4,368	3,000	3,600	4,320	10,920
6. Foundrymen (0.*3)					1,500	1,800	2,160	5,460
7. Fitters (1/*5)	600	720	864	2,184	1,000	1,200	1,440	3,640
8. Typists (0/*2)					1,000	1,200	1,440	3,640
9. Foreman (0/*1)					1,200	1,440	1,728	4,368

	USAID				KUMUDINI WELFARE TRUST			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
Personnel (Cont'd) Local								
10. Field Data Collector (*2/0)		2,440	1,728	4,168				
11. Laborers (0/*4)					500	600	720	1,820
12. Mill Manager (0/*1)					1,200	1,440	1,728	4,368
13. Internal Auditor(0/*1)					100	120	144	364
14. Driver/Messenger (1/0)	1,800	2,160	2,592	6,552				
15. Helper (1/0)	500	600	700	1,800				
Sub-Total B	5,300	8,800	9,340	23,440				
Sub-Total A + B	133,135	105,814	99,765	338,714	19,000	22,800	27,360	69,160

	USAID				KUMUDINI WELFARE TRUST			
IV. EQUIPMENT	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
A. Production of Stirling Engine in BD								
1. Welding Equipment	2,500			2,500	1,200	1,400	1,700	4,300
2. Lathe	15,320			15,320	3,000	3,600	4,300	10,900
3. Grinder	270			270	100	120	140	360
4. Milling Machines					1,500	1,800	2,100	5,400
5. Drill Press	1,500			1,500	800	950	1,150	2,900
6. Shaping Machines					2,000	2,200	2,600	6,800
7. Foundry Equipment					5,000	6,300	7,000	18,300
8. Hand Tools	2,200	600	40	2,840				
9. Welding Machines	400	600	100	1,100	1,600	1,900	2,250	5,750
10. 400/Grinder	3,400			3,400				
11. Materials	2,000	2,000	1,000	5,000	500	1,000	1,938	3,438
Sub-Total A	27,590	3,200	1,140	31,930	15,700	19,270	23,178	58,148

	USAID				KUMUDINI WELFARE TRUST			
IV. EQUIPMENT (Cont'd)	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
B. Survey, Testing and Evaluation								
1. Test Equipment for Stirling Units: Tachometer Stroboscope Torquemeter Temperature Equip. Electronic Service Kit	6,000	1,100	300	7,400				
2. Alternative: Milling Equipment Rubber Roll Hullers (2) Centrifugal Huller Disc Hullers (2) Cone polisher Abrasive Roll Huller	8,500	2,220		10,720				
3. Rice Testing Equipment: Sample Rice Huller Sample Rice Miller Sample Sizer Sample Aspirator Pyranometer Moisture Meters (3) Scales (3) Drying Oven	20,000			20,000				
Sub-Total B	34,500	3,320	300	38,120				
Sub-Total A + B	62,090	6,520	1,440	70,050	15,700	19,270	23,178	58,148

	USAID				KUMUDINI WELFARE TRUST			
	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total
V. REFERENCES AND PUBLISHING COSTS								
A. Books and Journals	1,100	800	600	2,500				
B. Printing and Binding	1,100	1,100	3,100	5,300				
Sub-Total	2,200	1,900	3,700	7,800				
VI. TAF PROGRAM MANAGEMENT COSTS	24,499	19,548	19,548	63,595				
Sub-Total	390,924	200,282	166,353	757,559				
VII. INDIRECT COSTS (22.2%)	86,785	44,463	36,930	168,178				
TOTAL PROJECT COSTS:	477,709	244,745	203,283	925,737	60,400	65,170	75,138	200,708

BUDGET EXPLANATIONS

I. DESIGN COSTS

Fees paid to Sunpower, Inc. for design and development, production of prototype stirling power unit and follow-up assistance in Bangladesh in developing a unit suited for commercial production.

II. FACILITIES

Building space for the project office, workshop and storage area will be provided by Kumudini Welfare Trust (KWT). Project expenditures will cover installation of electrical, water and sanitary facilities, provision of furnishings and installation of tools and equipment as well as any minor repairs and modifications to the existing buildings. The office will also be equipped with two air conditioners, a typewriter and a stencil cutter.

A. Purpose of expenditure

1. Project office - The project office will be the center of project operations in Bangladesh with facilities for conducting routine office work, coordinating the collection of field data and monitoring field testing. Information acquired will be housed at the office and the office will also prepare information on the project for dissemination.

2. Project workshop and storage - A project workshop will be set up for the full time use of project personnel for testing and modification of the Stirling power units and alternative milling equipment. The actual production of the intermediate and pre-production Stirling power units will be carried out in the KWT workshop by KWT workshop staff under the guidance of the Project Supervisor in a program phased to utilize Trust workshop facilites at times that they are not occupied with the maintenance of the KWT jute presses or river craft. Storage space will be provided for equipment, spare parts and materials and for paddy, husk and rice used in the process of testing the machinery.

B. Source of materials & equipment

Materials will be procured locally for installation of utilities. Air conditioners, typewriter and stencil cutter will be of U.S. origin.

C. Final disposition of facilities

At the end of the project all modifications and improvements to the buildings and office equipment will be left in place.

III. PERSONNEL

This category covers costs of all international consultants and local project office, research staff and production technicians.

IV. EQUIPMENT

EQUIPMENT FOR PRODUCTION OF STIRLING UNITS IN BANGLADESH

A. Purpose of expenditure

The equipment in this category will enable the project staff to carry out tests and to modify and adapt the Stirling power units and milling machinery as field testing and design modifications are carried out. Equipment listed here is typical of a shop equiped to work with machinerv and tc undertake basic metal-working operations. A more detailed breakdown of equipment categories follows:

1. Welding equipment -

   Arc welder

   Gas welding set exclusive of gas cylinders

2. Lathe

   General purpose workshop lathe of about 12" (swing) capacity, with accessories and measuring equipment.

3. Grinder

   General purpose bench grinder

4. Drill press

   Pedestal model equiped with angle and indexing vises and drill bits.

5. Hand tools

   A complete set of socket wrenches, open end spanners set of taps and dies, hand drill (electiic) and misc. other items such as files, pliers, etc.

6. Welding materials

   Consumable materials such as welding electrodes, rods, and welding gases.

7. Tool grinder

   A bench top tool grinder capable of sharpening milling cutters, drills, reamers, etc.

B. Source of materials and equipment

The source of tools and equipment will be the US and Code 941 countries.

C. Final disposition of equipment

The equipment listed in this category will remain with Kumudini Welfare Trust in order to strengthen their capability for producing the Stirling power units.

EQUIPMENT AND MATERIALS FOR SURVEY, TESTING AND EVALUATION

A. Purpose of expenditure

1. Test equipment for Stirling units:

   The tachometer, stroboscope, torquemeter and temperature measuring equipment will be used in monitoring the operation and performance of the Stirling power units in the workshop and in field test locations. The electronic service kit is for repair and maintenance of project equipment.

2. Alternative milling equipment:

   This will include: rubber roll hullers (2), a centrifugal huller, disc hullers (2 types), a small cone polisher and an abrasive roll huller. These units, after suitable adaptation, will be tested with the Stirling power units in the second and third phases of the project.

3. Rice testing equipment:

   The laboratory sample rice huller, miller, sizer and aspirator will be used in evaluating the performance of the alternative milling equipment and comparing these to traditional milling systems. The pyranometer will be used togather radiation data which will, together with rice drying tests, serve as a basis to estimate future needs for husk as a fuel for drying and the impact of this demand on the availability of husk as a fuel for the Stirling unit. An accurate laboratory moisture meter and two portable field units will be required along with three balances (scales) of different capacities. The laboratory oven is used for sample preparation and for calibrating the moisture meter.

B. Source of equipment

The analytical equipment and the rice testing equipment will be procured in the United States; however, the alternative small scale rice milling equipment will be procured from Code 941 countries where they are made and used. These would include

Sri Lanka, India, Thailand and the Philippines. This type of small scale rice milling equipment is not manufactured in the United States.

C. Final disposition of equipment

The final disposition of this equipment will be determined at the conclusion of the project. The equipment in this category, because of its specialized nature, would either be passed on to another project under the auspices of the Asia Foundation or it would be granted to local institutions which have research and development programs that could make effective use of such equipment.

V. REFERENCES AND PUBLISHING COSTS

A. Purchase of books, journals and other references related to stirling engines, husk furnaces, rice milling.

B. Costs related to printing, mimeographing, photocopying, binding and disbributing reports on the activities and results of the project

VI. TAF PROGRAM MANAGEMENT

Proportional costs of project support attributable to TAF/Dacca and TAF/ San Francisco staff, inputs.

V. PROJECT IMPLEMENTATION

The Asia Foundation, as grantee, will assist the Kumudini Welfare Trust, as subgrantee, in the implementation of the proposed project through the provision of supervision, technical consultation, publications, prototypes and specialized equipment and materials. All required contracts for consultations and foreign currency procurements will be arranged for directly by the Foundation on behalf of the Trust. Sunpower, Inc. will be responsible for all design and development activities related to the Stirling power unit.

The Foundation's resident staff, expatriate and local, will be responsible for monitoring the project and some management activities. They will work closely with the project personnel and the Managing Director of the Trust, Mrs. Joya Pati, and her staff and, together, will be responsible for efficiently carrying out the project. All accounting controls of external resources are maintained by the Foundation's Bangladesh office, but financial reporting and auditing is normally centralized in the Foundation's home office in San Francisco.

The Foundation will be responsible for submission of required financial and substantive reports to the primary donor according to agreed upon schedules as they relate to the progress of the project. The Foundation, in turn, will hold the Kumudini Welfare Trust responsible for specific reporting and evaluation requirements.

Kumudini Welfare Trust will provide space for a project office and space for project test facilities. Prototype production will be done together with the existing Trust workshops which are located near to the planned site for the project office and test facilities.

Table III shows the project Implementation Plan. The following sections describe the functions and responsibilities of key personnel, the project implementation tasks and activities and the procurement schedule.

A. PERSONNEL FUNCTIONS

Specific scopes of work will be prepared by the Foundation for all project consultants and personnel. The main staff functions are briefly described below.

TABLE V

TAF/Rice Implementation Plan
Year 1

Phase One	MONTHS 1	2	3	4	5	6	7	8	9	10	11	12
I. Stirling Unit Design (Sunpower/Ohio)	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
A. Husk Consultancy (Ohio)	X	X		X		X		X		X		X
B. Stirling Engine Consultancy (Ohio)	X			X				X				X
C. Power Study (BD)			X X X X									
I. Prepare Office & Workshop		X X X X	X X X X	X X X X	X X X X	X X X X						
A. Order Equipment	X X X X											
B. Receive, Install Equipment			X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X		
I. Collection of Data on Husk Utilization					X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X
V. Tests of Milling Equipment									X X X X	X X X X	X X X X	X X X X
V. Planning, Evaluation Reporting	X			X				X				X

TABLE V

TAF/Rice Implementation Plan
Year 2

Phase Two	MONTHS 13	14	15	16	17	18	19	20	21	22	23	24
I. Stirling Unit												
A. Prototype Testing (BD)	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X
B. Intermediate Fabrication (BD)			X X X X	X X X X	X X X X	X X X X	X X X X	X X X X				
C. Intermediate Testing (BD)									X X X X	X X X X	X X X X	X X
D. Sunpower Project Leader (BD)						X						
E. Sunpower Engineer (BD)						X X X X						X X
F. Husk Consultant (BD)						X						
II. Collection of data on Husk Utilization	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X
III. Tests of Milling Equipment	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X	X X
IV. Planning, Evaluation and Reporting						X						

TABLE V

TAF/Rice Implementation Plan
Year 3

Phase Three	MONTHS 25	26	27	28	29	30	31	32	33	34	35	36
I. Stirling Units												
A. Intermediate Testing (BD)	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X						
B. Pre-production Fabrication (BD)	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X						
C. Pre-production Testing (BD)					X X X X	X X X X	X X X X	X X X X	X X X X	X X X X		
D. Sunpower Project Leader (BD)				X							X X	
E. Sunpower Engineer (BD)				X X X X								
F. usk Consultant (BD)				X							X X	
II. Collection of Data on Husk Utilization	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X						
III. Tests of Milling Equipment	X X X X	X X X X	X X X X	X X X X	X X X X	X X X X						
IV. Planning, Evaluation and Reporting						X					X X X X	X X X X

1. Project Supervisor

   a. Will be responsible for activities in Bangladesh to:

      (1) set up the project office and workshop,

      (2) cooperate with the Sunpower engineer in carrying out the power study,

      (3) order and set up project equipment,

      (4) design and implement the milling equipment evaluation and husk utilization survey,

      (5) coordinate the local manufacture and testing of Stirling power units.

   b. Will participate in the selection of materials and manufacturing methods to be used in producing the Stirling power unit in the United States.

   c. Will participate in all project evaluations at Sunpower and in Bangladesh.

   d. Will prepare project reports and arrange their dissemination.

2. Project Administrator

   a. Will assist project supervisor in the administration of the project and the procurement of project equipment.

3. Sunpower Project Leader

   a. Will be responsible for development of initial design and development of the Stirling power prototype in Ohio.

   b. Will participate in all four planning and evaluation meetings in Ohio (at months 1, 4, 8, 12).

   c. Will participate in the three planning and evaluation meetings in Bangladesh (at months 18, 24, 28) and in the preparation of the final report at month 33)

4. Sunpower Engineer

a. Will participate on behalf of Sunpower in design, fabrication and testing of Stirling power unit.

b. Will be responsible, along with the project supervisor, to make the initial determination of the power output required to satisfactorily operate a No. 4 rice huller.

c. Will participate in the four planning and evaluation meetings in Ohio (at months 1, 4, 8, 12).

d. At three points during Phases II and III the Sunpower engineer will travel to Bangladesh and assist the project staff in working out technical problems that arise in production and field testing. These three visits of about a month each will be timed to overlap with the three scheduled review and evaluation meetings scheduled for months 18, 24, and 28.

5. Rice Husk Consultant

a. Will be the resource person for information on rice husk furnace design.

b. Will participate in the four planning and evaluation meetings in Ohio (at months 1, 4, 8, 12) and will visit Ohio at months 2, 6, and 10 to assist Sunpower in furnace design.

c. Will participate in the three planning and evaluation meetings in Bangladesh (at months 18, 24, 28) and in the preparation of the final report at month 35.

6. Stirling Engine Consultant

a. Will serve as a resource person on Stirling technology.

b. Together with Sunpower personnel the consultant will evaluate technical aspects of the Stirling design in the four planning and evaluation meetings during Phase I (at months 1, 4, 8, 12).

B. PROJECT ACTIVITIES

This project incorperates several separate but inter-related activities. And these activities are in some cases split between Sunpower in the United States and Bangladesh. The planning and review activities described here are critical to insure adequate communication and feedback between various components of the project.

Phase One

Organizational Meeting (Athens, Ohio 2 days)

At the beginning of the project there will be an initial meeting with Sunpower personnel, the Project Supervisor, the Rice Husk Consultant, the Stirling Engine Consultant and a representative of The Asia Foundation. At this time any final implementation details of the overall project will be clarified and further specified as is deemed necessary. The subcontract between The Asia Foundation and Sunpower, Inc. will be finalized at this time. The Project Team will make an initial determination about the design concepts for the Stirling engine and the husk furnace. The team will also review and approve the list of equipment to be procured.

1. Stirling Unit Prototype

Sunpower will do the design and prototype development in Athens, Ohio. They will be assisted by the husk consultant who will serve as a resource person in the development of the rice husk furnace. The final determination of the power of the Stirling unit will be made on the basis of a field study of milling power requirements which will be made jointly by the project supervisor and the Sunpower engineer. The Sunpower engineer will travel to Bangladesh for a month during the first part of Phase I.

Monitoring of design progress will take place at three points in the first Phase tentatively set at months 4, 8, and 12. At these times the Rice Husk and the Stirling engine consultants and the project supervisor will travel to Ohio to review and evaluate progress and decide on any changes in planned activities The final (month 12) meeting will include the participation of TAF personnel, and possibly USAID staff to determine whether Phase I criteria have been satisfactorily met and whether or not to continue to Phase II.

2. Set Up Office and Workshop

The building which will house the project office and workshop will be provided by Kumudini Welfare Trust. While these buildings are already in place they will have to be modified and supplied with electricity, water and sanitation facilities. This work will commence in month 2 and is expected to be completed by the end of month 6. Installation of equipment will be completed by the end of month 10.

3. Rice Husk Utilization Survey

The equipment needed for this survey will be procured, the survey methodology developed, data investigators hired data collection started. By the end of Phase I, the preliminary data on husk utilization will be examined to determine if the preliminary projection of availability of rice husk in rural areas will be sufficient to satisfy the expected fuel needs of Stirling powered rice mills in rural areas.

Progress on the survey and its preliminary results will be reported at each review meeting (months 4, 8, 12).

4. Alternative Milling Equipment

The alternative milling equipment will be procured and set up for testing in the project workshop. Initial tests using electrical power will be run to establish what the normal performance of this equipment is. Of particular interest are the power requirements and milling capacity of the alternative equipment. These factors, will help determine, in part, the suitability of this equipment for use with the Stirling unit. Preliminary results will be reported in the three review meetings.

Phase Two

1. Stirling Unit

In Phase II the prototype Stirling unit will be shipped by airfreight to Bangladesh and the local fabrication of four intermediate units of the Stirling unit will commence. The Sunpower engineer will come to Bangladesh twice during this Phase for a

month each time in order to assist in developing production methods and solving any technical problems.

Progress reviews in this phase will occur at months 18 and 24. The Sunpower project leader, Sunpower engineer and husk consultant will participate with the project staff in these evaluation meetings. The 24th month evaluation will also be attended by TAF, USAID and Kumudini representatives. Based on the evaluation results, the decision of whether to proceed with Phase III will be made.

2. Husk Utilization Survey

Field data will be collected for a full year so that any seasonal variations in husk use will be noted. This survey will involve periodic visits to representative areas of Bangladesh to verify actual use patterns. By the end of this phase a clear determination will be possible regarding alternative uses of rice husk and the projected availability of husk as a fuel for Stirling power units.

3. Alternative Milling

The alternative milling equipment will be tested together with the Stirling power unit to verify whether the units are compatible in respect to power, capacity, product quality and system costs. The husk resulting from the different milling systems will be evaluated with regard to its utility as a fuel for the Stirling unit. In the case of excess husk, its utility for alternative uses such as animal feed will be assessed.

Phase Three

1. Stirling Unit

The objective of this phase is to make necessary modifications in the design and production methods to insure that the final design is suited for commercial production. As a part of this activity jigs and fittings will be designed which would be suitable for use by small manufacturers. Full use will be made of existing workshop facilities by sub contracting specialized jobs such as pattern making, foundrywork, pressing, forging, etc.

During this time field testing will continue with the intermediate units to obtain information on long term wear. These results will also be incorporated in the pre-production design. Four units of the pre-production unit will be made and these will be field tested between the 29th and 34th month. The field testing will be designed to determine performance, cost projections and the acceptability of the pre-production units to rural millers. During the third phase the Sunpower engineer will make one visit of one month (month 28) to assist in development of the manufacturing methods for commercial production of the Stirling units. The Sunpower project leader and the husk consultant will participate in a review meeting at month 28 for one week and in month 35 they will participate in the preparation of the final report.

2. Husk Utilization

The collection of information on husk utilization will be completed by the end of month 30. This information will form part of the final report along with an evaluation of the present and future potential for rice husk as a fuel for small rice mills. It will include :

a. An enumeration of the alternative traditional uses for husk correlated to information on regional and seasonal variations in availability, econmic value and use.

b. A discussion of the alternative uses for husk in Bangladesh which might be introduced in the near future.

c. Projections as to alternative uses of the Stirling unit using husk as the fuel where excess husk is available.

3. Alternative Milling Equipment

The tests of alternative milling equipment will evaluate ease of operation and maintenance, milling capacity, husk consumption of the total milling system and utility of the by-products. This will be completed by month 30. In addition to this information, the final report will include projections as to probable costs of these alternative systems compared to the traditional steel huller.

C. PROCUREMENT

Procurement is accomplished directly by the Foundation, either locally, through its other field offices in Asia, or centrally from the home office in San Francisco. Procurement is conducted within the existing regulations of the primary donor with respect to origin of goods. On major standard items, competitive pricing is the normal practice before procurement. The Foundation will maintain procurement records in its Dacca office and copies of financial records associated with other project events will be provided by the San Frnncisco office. These records will be open for inspection by the primary donor's project monitors and auditors. The equipment to be procured in the United States will be ordered in the first month of the project for shipment to Bangladesh.

The lathe and alternative milling equipment which is to be procured from India and other Asian countries will be ordered in the Third month of the project.

VI. REPORTS AND EVALUATION

The success of the project depends upon close communication among the groups involved in design development, field testing and local production and the consultants who will provide assistance in design and evaluation. To ensure close communication and to provide for concise reporting, both during the project and at its completion, a comprehensive system of review, evaluation and reporting will be an integral part of the project.

As stated above, these activities will be composed of an initial organizational meeting, periodic reviews in Ohio of the progress of the design of the Stirling power unit, periodic reviews in Bangladesh of the progress in field testing and local production and consultancy assistance in the design of the rice husk furnace component of the system. Reports will be pared at each review point (months 1, 4, 8, 12, 18, 24, 28) as well as the final report at the conclusion of the project.

A. REPORTS

1. Project Status Reports

The Foundation agrees to submit to USAID project reports describing progress in implementation as outlined in Section V above.

These reports, in a minimum of ten copies, shall be provided to USAID according to the Implementation Plan. In addition, TAF will insure that documentation on the Stirling power unit is presented at conferences and seminars both internationally and in Bangladesh. Circulation of project documentation is an output of this project. USAID will be kept informed about all documentation distribution.

2. Financial Reporting

Financial statements and requests for advances will be submitted by TAF to the USAID/Dacca Controller at the beginning of every quarter unless otherwise agreed to by the Grantee and the USAID Grant Officer.

B. EVALUATION

At the end of each project phase there will be an evaluation to determine project achievement and whether the project should proceed to the subsequent phase. As noted, for each evaluation phase criteria are provided in this project (see Table II). At the first organizational meeting of Phase I, the technical consultants will review the critera provided in Table II, ascertain whether these need further amplification or greater specificity and inform TAF and USAID of any recommended changes. For each phase and evaluation a report will be prepared which:

1. addresses project accomplishments in relation to project criteria,
2. incorporates all design, development, production, testing and survey results,
3. identifies material and equipment needs for subsequent manufacturing, and
4. recommends any project design modifications deemed necessary for the next project phase to be successful. Any project replanning requirements will be communicated to TAF and USAID for appropriate action.

If project results do not meet the evaluation criteria at each phase, the project is terminated. The evaluations will take place sufficiently before the end of each phase to permit adequate time for arranging subsequent project funding. In the first project evaluation, the project consultants, TAF and possibly USAID will

participate. In all subsequent evaluations, the consultants, TAF, USAID and Kumudini Welfare Trust will be involved.

At each phase, USAID will ultimately determine whether the project should proceed to the next Phase.

VII. STANDARD PROVISIONS

The following Standard Provisions, Attachment B, do not apply to this grant 2, 6, 8, 10, 12, 16, 19, 21, 23, 24, 25 and 27.

A N N E X A

STIRLING ENGINE AS A POWER SOURCE FOR DEVELOPING COUNTRIES

THE STIRLING ENGINE AS A POWER SOURCE FOR DEVELOPING COUNTRIES

BEST AVAILABLE DOCUMENT

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TABLE OF CONTENTS

I. THE STIRLING ENGINE

II. PERFORMANCE OF EARLY STIRLING ENGINES

III. RECENT DEVELOPMENTS IN STIRLING ENGINES

A. ROTARY SHAFT STIRLING ENGINES

B. FREE PISTON STIRLING ENGINES

C. LIQUID PISTON PUMP

IV. APPLICATIONS FOR STIRLING ENGINES IN DEVELOPING COUNTRIES

V. POTENTIAL FOR MANUFACTURE OF STIRLING ENGINES IN DEVELOPING COUNTRIES

A. ROTARY SHAFT STIRLING ENGINES

B. FREE PISTON STIRLING ENGINES

VI. CHOICE OF APPLICATION FOR STIRLING ENGINES

VII. CONCLUSIONS

VIII. RECOMMENDATIONS

I THE STIRLING ENGINE

The Stirling engine originated with the work of the Rev. Robert Stirling in Scotland in 1816. It competed successfully for a time with steam engines, being safer to operate and having lower fuel consumption and a simpler mechanism. They became quite popular in the late 1800s and early 1900s as solid fueled water pumps for domestic use, being easy to operate, quite and durable. They fell into disuse with the advent of small light weight gasoline engines and widespread electrification in developed countries but have lingered on until recent times as kerosene fueled fans in areas without electricity.

The essential characteristics of the Stirling engine are as follows:

1) It is an external combustion heat engine which cycles a closed volume of air or other working gas through a sequence of steps in which the gas is alternately heated and cooled. Mechanical work is extracted from the expanding and contracting working gas by having it act against a piston. Although simple in concept, Stirling engines become complex in the manner in which the working gas is moved between the hot and cold spaces and made to operate the power piston.

2) The fact that the fuel is not burned inside the engine allows it to use any fuel, for example coal or rice husk to provide the necessary heat. It does not require the refined liquid fuels that are essential for gasolene, kerosene or diesel engines though the Stirling engine can be operated on these also.

3) The Stirling engine is mechanically very simple. It has no valves, cam shafts, fuel injectors, ignition components or other precisely machined parts. All of its sliding surfaces operate in the cool parts of the engine making it possible to use such materials as greased leather as piston

seals rather than lubricated metal piston rings. The Stirling engine is compact in relation to steam engines needing no boiler though it is large in comparison with internal combustion engines.

4) While it is mechanically simple the Stirling engine requires careful analysis and design to arrive at the correct proportions for the heat exchanger and other components in order to achieve reasonable power and efficiency. Once this complicated design phase has been completed the Stirling engine can be much simpler to make than a comparable internal combustion engine.

5) Stirling engines can be made with commonly available materials such as stainless steel greatly improve performance, reasonable results may be achieved with careful design and use of ordinary mild steel, cast iron or aluminum.

II. PERFORMANCE OF EARLY STIRLING ENGINES

The early Stirling engine was severely limited by both the low level of metallurgical knowledge at the time and even more importantly, by the lack of understanding of the complex thermodynamic and fluid flow phenomena which are vital to high performance designs. Despite this, these engines were bought in large numbers for water pumping purposes because they easily outperform windmills and other alternatives available before the advent of the small gasolene engine and electric motor. Records show that in U.S. domestic service it was not uncommon for a coal fired Stirling engine to pump water for 20 years with very little maintenance, limited to an occasional greasing of journal bearings and replacement of a simple leather piston seal. Power and efficiency were, however quite low. A 1906 catalog for Ericson engines (a Stirling engine manufacture in the U.S.) claimed only 150 watts output - about 1/5 horsepower for a machine weighing about 250Kg with a fuel efficiency of only 1 percent.

A steam engine might give about 10 percent efficiency by comparison. Fuel was, of course very cheap but this performance was never-the-less mediocre even for the time. Again, the reason was inadequate metallurgy limiting the hot end temperature and poor understanding of heat transfer, fluid flow and thermodynamics.

III. RECENT DEVELOPMENTS IN STIRLING ENGINES

In spite of the absence of practical application for Stirling engines since the turn of the century there has been a continuing if not extensively supported, interest in the potential of the Stirling engine as a multi-fuel external combustion power system. Since the second world war there has been an expansion of both theory and practice in Stirling engine development.

In addition to the various designs of rotary shaft Stirling engines that have been evolved, some radically different engine designs based on the Stirling cycle have emerged in recent times. In 1964 a free piston Stirling engine was developed by W.T. Beale at Ohio University. At Harwell, England a liquid piston pump operating on the Stirling cycle has been developed and the same group has been working on a diaphragm Stirling engine.

Applications for Stirling engines are proposed for a wide variety of uses. However funding has been concentrated heavily on the development of Stirling engines for automotive use, closely followed by a range of sophisticated applications from artificial hearts to power supplies for satellites and cooling systems for comestic, commerical and military use. Tables I and II summarize some of the recent work being done on Stirling engines and the programs that are presently being supported by U.S. Government funds.

TABLE I

RECENT WORK ON STIRLING ENGINES

(1979)

COMPANY	TYPE OF WORK	EQUIPMENT SUITABLE FOR THIRD WORLD	C O M M E N T S
Philips (Holland)	Automotive Stirling Licenses to MAN, United Stirling and G.E. and Ford (these two have since discontinued activities)	200 watt free piston Stirling generator under development	The first workers on the modern Stirling engine. Concentration on automotive but some work on third world applications. Possess computer design capability.
Sunpower, Inc., Athens Ohio USA	Small free piston and rotary shaft engines intended for third world use. Solid fuel combustion. Initiated free piston work. Transfered some technology to MTI.	100 watt free piston generator Duplex Stirling heat pump, water pump, low pressure air rotary shaft engine with solid fuel burner. Working prototypes of all models have been made and are available for sale.	Orignator of the free piston Stirling engine. Only source of free piston engines. Sunpower has developed a computer based system for designing both free piston and rotary shaft Stirling engines.
MTI Albany, N.Y.USA	Advanced design for automotive and aerospace applications. Uses Sunpower computer code.	No working prototypes, at present concentrating on high performance.	Worked for 3 years with Sunpower to develop free piston design capability. Hardware program just starting under DOE sponsorship for automotive use.
ERG, Inc Oakland Calif. USA	Ultra-high performance alternators and heat pumps	No prototypes available for public use. Concentrated on sophisticated designs	Oriented towards maximum thermal efficiency with elaborate heat exchangers
Harwell UK	Limited work on liquid piston pumps. Diaphragm linear alternators.	40 watt diaphragm engine in use for special purposes	Harwell originated the liquid piston low pressure air engine for water pumping, but has devoted most of its effort on the diaphragm engine alternator.

Table I cont'd...

COMPANY	TYPE OF WORK	EQUIPMENT SUITABLE FOR THIRLD WORLD	C O M M E N T S
Metal Box Co. Calcutta, India	Liquid piston water pump commercial Prototype development	125 watt liquid piston water pump under development	MB hopes to have its liquid piston pump in production within two years for water pumping in farms of less than 2 hectares.
University of Reading (P.Dunn) England	Fluidized bed combustion, heat pipes, simple crank engines	None	Most work on fluidized bed combustion. Stirling engines a Secondary interest.
University of Calgary (G.Walker) Canada	University research on theoretical aspects	None	Walker has written the definitive text on Stirling engines (Oxford University Press) 1980
United Stirling Sweden	Automotive work allied to MTI and US automotive program and US solar central power station program		Licenses of Philips, a leader in automotive Stirling engines. Stirling Power Systems is a USA subsidiary.
MAN W.Germany	Large engines for ships and submarines also some work on large (30 kw) solar engines.		Heavily funded elaborate program to produce gas fired heat pump for commerialial and residential use in USA.

TABLE II

PRESENT US, GOVERNMENT FUNDED STIRLING ENGINE DEVELOPMENT PROGRAMS

PROGRAM	DESCRIPTION	COMPANIES INVOLVED
Automotive	$100 million over next 8 years to produce alternative power plant to present internal combustion engine	M.T.I. Albany, N.Y., with United Stirling (Sweden) and American Motors Corp.
Central Solar Power	Large numbers of relatively large and complex (20 - 30 Kw) Stirling engines and parabolic collectors to produce megawatts of electrical power	M.T.I.,United Stirling (Sweden),G.E.
Large solid fuel stationery power generators	High efficiency, large, heavy, long life engines for use with solid fuels	M.A.N. (Germany),G.E. Philips (Holland)
Military Programs	Military and space use	Large companies Secret programs
Appropriate Technology for Developing Countries	No programs funded	None Proposals have been submitted to USAID by Sunpower and are under consideration

A. Rotary Shaft Stirling Engines

Towards the end of the Second World War Philips of Holland was developing a small Stirling powered generator to use as a multifuel power supply for mobile radio units for military use. The advent of the transistor at about this time so dramatically reduced the power requirement of electronic equipment that it was feasible to operate mobile units on batteries thus obviating the need for a mobile power supply. Philips, and subsequently other companies, then turned their expertise in Stirling engines to the development of a powerful and efficient automotive power unit. Funded heavily by the U.S. Government these Companies worked towards the extremely difficult goal of replacing the present automotive internal combustion engine with a more fuel efficient, low pollution Stirling engine. However, for automotive requirements of light weight and high power, Stirling engines must use very high working pressures, high temperature heaters, and light working gas- helium or hydrogen. As a result they face exceptionally challenging design problems in their seals, lubrications and heater head metallurgy. Consequently the modern Stirling engine has not yet come into use in automobiles.

In an effort to retain the simplicity of the original Stirling engine while improving its performance Sunpower, Inc. has used advanced design techniques to optimize the design of a simple low pressure Stirling engine using air as the working fluid. Starting with a 1900s design that originally produces 40 watts of power Sunpower was able to produce a prototype that produced more than 800 watts.

B. Free Piston Stirling Engines

The free piston Stirling engine reduces the number of moving parts to two and incorporates a totally sealed system. The reduced number of moving parts contributes to less frictional losses (higher efficiency) and the ability to totally seal the system facilitating the use of light gases such as hydrogen and helium under high pressure without the sealing problems associated with rotary shaft Stirling engines.

Sunpower has applied the free piston Stirling engine to electricity generation (linear alternator), water pumping and cooling systems based either on an intertial pump for compressing conventional refrigerators or by using one Stirling engine to drive a second Stirling engine arranged as a cooling unit.

Based on Sunpower's initial work on free piston Stirling engines a number of other companies are now working on a range of applications for the free piston Stirling engine (see Table I).

C. Liquid Piston Pump

In England, a group at Harwell have invented a uniquely simple liquid piston Stirling engine which uses low pressure air as its working gas, and ocillating columns of water as pistons instead of the usual pistons connected to a crank. This Harwell concept is now being developed for near-term commercial sale by the Metal Box Company of India. Metal Box estimates that their coal fired water pump will pay for itself in two years of use by providing irrigation for small farms in rural India.

IV. APPLICATIONS FOR STIRLING ENGINES IN DEVELOPING COUNTRIES

Developing countries presently have the need for small, simple power units with multi-fuel capabilities that brought the Stirling engine to popularity in western countries in the last century. In many rural areas of the third world electricity in not available and the steadily escalating price of petroleum products put the internal combustion engine increasingly at a disadvantage. Meanwhile the steady improvements being made in Stirling engine technology make these power units increasingly attractive as an alternative power source.

Ironically most of the development funds for Stirling engines have been concentrated on the most complex and so far illusive objectives of an automotive power unit and other sophisticated applications for the developed world. In contrast to these highly sophisticated uses there are numerous uses for small multi-fuel power units in developing countries

for which the presently available Stirling technology can offer practical solutions. Those very features which have proven so difficult to achieve in sophisticated applications of Stirling engines are for the most part not necessary for successful use in developing countries, namely:

1) High power to weight ratio
2) High speed
3) Very high fuel efficiency
4) Quick response to speed changes

With the increasing interest and commitment to support the development of renewable energy resources in the developing world it may be expected that the application of Stirling engine technology in this area will attract more support in the future.

Some of the uses to which Stirling engines might be applied in the developing world are:

1) Power Unit For Rice Milling

The Stirling engine would provide an ideal means by which to exploit the tremendous potential of energy available in rice husk. The first logical use would be to provide the power required for the rice milling operation itself. As only a fraction of the husk produced would be required for powering the rice mill the remainder could be used to generate for parboiling, for other traditional uses of rice husk or for powering other operations.

2) Irrigation

The simplicity of construction and maintenance and its durability make the Stirling engine attractive as a power unit for irrigation. In many developing countries the low power to weight ratio of a simple Stirling engine would not be a serious problem with small irrigation units of from 1 to 5 horse power as these units, though bulkier than internal combustion engine equivalents, would still be portable and would have the advantage of operating on rice husk as well as on kerosene,

diesel fuel and natural gas. With further development of collector systems the Stirling engines could also utilize solar energy.

3) Electricity Supply

Small free piston Stirling engine generator units are presently available which provide 100 watts of electrical power. These units provide enough power to operate a television set in addition to lights, fans and other power requirements. The projected production cost of such units is in the range of $140 and the efficiency is already high enough that $0.10 to $0.15 of kerosene (at prevailing costs in Bangladesh) would be sufficient to provide power for a full evening's use of 4 to 5 hours. Programs for educational and extension use of television and radio could capitalize on this type of power supply for rural areas without electrification. Power supplies of any size could be made, thus offering the possibility of multi-fuel power generation to provide electricity to whole villages and even towns where alternative fuels are available. Once put into production at a reasonable cost, small power units would most likely find a ready market in the private sector and this additional volume of sale would help to keep the unit price low.

4) Small Scale Refrigeration Units

The Stirling based cooling system could find application in providing small, portable and efficient cooling units operating on kerosene for transporting vaccines and other supplies both for medical and veterinary uses. Again, such units would most likely find a market in the private sector if made available commercially.

5) Power for Agriculture Operations

In many parts of the developing world agricultural mechanization is in its infancy. As the need for power units for threshers, dryers and other agricultural equipment develops Stirling engines could play a significant role in supplying the needed power while using locally available energy sources. The use of Stirling engines with grain dryers is particularly appealing as the waste heat from the Stirling engine could be used to heat the grain as the engine itself drives the ventilating fan and perhaps moves the grain.

6) Mobile Power Units

The scope is there for using Stirling engines as power units for vehicles, power tillers and boats, however one then becomes involved in all the complexities previously mentioned in relation to the automotive engine development programs. Perhaps as these heavily funded programs come up with useful results, some of these could be applied to the developing world.

V. POTENTIAL FOR MANUFACTURE OF STIRLING ENGINES IN DEVELOPING COUNTRIES

Stirling engines for use in developing countries should be designed to be made with locally available materials and workshop facilities Manufacturing techniques which would be considered routine in developed countries may require machine, materials or skills quite beyond the reach of manufacturers in developing countries. On the other hand, labor intensive and skilled machine tool operations that would be too costly in developed countries can be used in developing countries to produce high quality and reasonably priced components where skilled labor costs are low. With proper care in design, modern Stirling engines of excellent performance could be manufactured in simple shops accustomed to automotive, steam engine or electric motor repair work.

A. Rotary Shaft Stirling Engine

The low pressure air engine uses simple plain or roller element

bearings, leather cup seals on the piston, crank case and cold cylinder of steel, cast iron or aluminum and a cast aluminized or ceramic heater head. It is possible to consider cheap ceramics with their high temperature capabilities because the low pressure air engine puts very little tensile stress on the brittle materials and has far less likelihood of cracking it than does the high pressure engine. Fortunately the hot parts of the engine do not require precise dimensions and can be considered for fabrication as ceramic castings, where dimensional changes tend to be large during curing.

Because of the absence of precision machined parts the rotary shaft Stirling engine would be competetive in cost with internal combustion engines and where made insmall workshops with low overhead costs the Stirling engine would be likely to have a dramatically lower cost per horsepower.

B. Free Piston Stirling Engine

Free piston Stirling engines, which are even more simple in construction than low pressure air rotary shaft engines, do require quite close fits on their sliding parts, but this can be done by hand lapping matched pairs which is a labor intensive but very effective method of getting precise fits without expensive machinery The free piston engine, being completely sealed and lubrication free, is most likely to have an exceptionally long and trouble free life, and for this reason is, despite its finer tolerance requirements, a strong contender with the low pressure air engine for use in developing countries.

The free piston Stirling engine is especially useful as a water pump, in which use it can be made extremely simple in construction. In outward appearance it is a two to three feet long cyclinder, which when heated at one end will oscillate up and down with the bottom of the cyclinder acting as a piston in a postive displacemen pump.

Another application for the free piston Stirling engine is as a heat driven pump. Here a unit with only three moving internal parts is heated on one end to produce freezing cold at the other end.

A free piston Stirling generator uses an internal coil connected to one of the moving parts to generate electricity. In these engines the heater head would be best made of stainless steel which is available in Bangladesh, for example, at $3.00 per pound. The heater head would only require a few pounds of stainless steel at most for a small free piston engine.

Working prototypes of all of these applications in free piston Stirling engine design have been made by Sunpower, Inc. However, in order to produce designs suited for manufacture in developing countries and to insure the requisite durability and ease of operation further development work will be necessary.

VI. CHOICE OF APPLICATION FOR STIRLING ENGINES

Innumerable articles, books and conferences have generated increasing familiarity with a variety of new technologies including the many possible applications for Stirling engines. The acutal introduction of any one of these applications must be done carefully and selectively to assure appropriate adoption and consequent benefit.

By selecting an application where the need for a power unit already exists and where are significant benefits from the use of the Stirling engine it may be possible to accelerate the usually slow process of introducing a new device. Once a Stirling engine has found its way into everyday use, the introduction of other new and different types is likely to be effected more easily.

Rice processing is a case where mechanical power has been readily adopted particularly when possible by means of electrification. Small rural rice mills in developing countries have been particularly sensitive to the escalating costs of energy as that represents their major operating cost. It is not surprising that small rice millers

have shown a great deal of interest in the possibility of using rice husk as a power source for their mills.

It will be appreciated if a Stirling engine power unit could be developed for use with small rice mills there would be huge and virtually instant market for the units with tons of thousands of such small mills now in operation and similiar numbers being set up as electrification reaches more rural areas. By using the excess husk to power irrigation pumps the attractiveness of the Stirling engine power unit could be made even greater.

By developing a low pressure, rotary shaft, air engine for this purpose the manufacture and maintenance of the engine can be brought well within the capability of local manufacture in developing countries. The power of the unit to be introduced would be critical to the success of the project and could only be determined after a careful assessment of power requirements of small mills and alternative uses for the engine.

If one takes the hypothetical case of a small rice mill with a capacity of ¼ ton of paddy per hour then the mill, while it is operating, will produce husk at the rate of 50 kg. per hour (husk comprises 1/5 the weight of the paddy). The energy in the rice husk produced at this rate is equivalent to 260 hp per hour. Taking the efficiency of the Stirling engine to be 10 percent (a conservative figure) then the actual power available from the ¼ ton per hour mill is about 26 hp per hour. Such mills presently use 5 hp engine so that if a Stirling engine of this power were used an excess of 21 hp per hour would be available. Using a similiar Stirling engine linked to a water pump of ½ cusec capacity it would be possible to operate the water pump for four hours (20 hp per hour) for every hour that the mill was operated. It is likely that the efficiency of the Stirling engine could be increased to 20 percent or more and this would then double the useable energy from the husk.

Considering the total rice production of Bangladesh at about 15 million tons then the resulting three million tons of rice husk is equivalent to 4.2×10^{16} joules/year (taking the heat energy

of rice husk to be 14 X 10^6 Joules/Kg). If this amount of energy were converted to power at 10 percent efficiency this is equivalent to a continuous (year 'round) power output of 130 megawatts. Even if only a portion of this potential power could be tapped it would have a significant impact on conversation of electricity and imported fuels and this energy would be available in the remotest parts of the country.

VII. CONCLUSIONS

A. The modern Stirling engine has been developed to a point where it could be applied to power production in both small and large sizes and with designs suitable for local manufacture and local fuels (rice husk, coal, wood, etc.) in developing countries.

Prototypes having good performance exist which are capable of producing electric power, mechanical power, refrigeration and pumping water, all without any intermediary shaft power transfer.

B. The essential remaining technical task is to apply the existing highly developed design methodology and working experience to the design of machines specifically suited to carefully chosen applications in developing countries and to have these machines manufactured in the countries of their intended use.

C. Rice milling offers an application where there is likely to be an immediate interest in Stirling engines as power units and where an ideal fuel (rice husk) is readily available.

D. The selection of power for which the Stirling engine will be designed is critical to the success of its introduction. The actual power requirement of small rice mills will first have to be accurately assessed as well of those of alternative uses as for example small irrigation pumps.

E. It is estimated that for a 5 hp equivalent Stirling engine to operate a small (½ ton per hour) rice mill only 1/5 of the rice husk would be required leaving 4/5 of the rice husk to power a similiar engine for other purposes such as irrigation. Thus for every hour that the rice mill is operated a ½ cusec pump could be operated for 4 hours.

F. The total amount of rice husk produced in Bangladesh, if converted to power by existing Stirling engine technology (10 percent efficiency) would produce a continuous power output all year long of more than 130 megawatts. Moreover, this power would be available in the most remote parts of the country, wherever rice husk is available. Even if a small portion of this potential energy could be utilized through the use of Stirling engines it would have a significant impact on these aspects of development in rural areas that require a source of power.

VIII. RECOMMENDATIONS

Because of the immediate applicability of Stirling engine technology as a power source for rice milling it is proposed that a rotary shaft air engine be developed for use in small rural rice mills. The following sequence of activities could be considered:

1) Determination of optimum size of Stirling power unit
   a. Accurate assessment of power requirements of small rice mills.
   b. Assessment of power requirement for alternative uses i.e. irrigation.

2) Initial design and testing
   a. To be carried out by the company undertaking the design of the Stirling engine in cooperation with a field oriented project in the country of application
   b. Design of engine will be based on computer optimization and initial prototype must meet previously determined performance levels.

3) Production of prototype in country of use
   a. Local production of prototype using specifications developed in the initial design and testing.
   b. The developer of the Stirling engine design will cooperate with a local workshop in this phase.
   c. Locally produced prototype will be tested in actual use in a rice mill.

4) Production of units for extensive field trials
   a. Several units, modified as necessary from previous tests, will be produced locally and placed in rural rice mills for extensive field trips and evaluation.
   b. Close contact will be maintained with mill operators to assist in training in the use of the Stirling engines and to determine what additional modifications may be necessary.
   c. Modification of units as necessary to insure easy and trouble free operation.

5) Release for local production.

A N N E X B

RICE HULLS AS A SOURCE OF POWER

FOR SMALL RICE MILLS IN BANGLADESH

BEST AVAILABLE DOCUMENT

AATC Information Bulletin
No. 6

RICE HULLS AS A SOURCE OF POWER FOR SMALL RICE MILLS IN BANGLADESH

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April 1979

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RICE HULLS AS A SOURCE OF POWER FOR SMALL RICE MILLS IN BANGLADESH

1. INTRODUCTION

The rice kernel is surrounded and protected by a tough covering or hull which is composed mostly of cellulose and silica. Unlike other cereal grains (i.e. wheat) the hull is not removed during harvesting and threshing and remains on the kernel during storage and during parboiling. Rice milling thus involves the removal of the husk as well as the germ and a portion of the bran layer from the kernel.

Unlike germ and bran, rice hulls have little nutritional value, even for cattle, and the primary use for hulls in developing countries is as fuel. Parboiling is the most common purpose for which rice hulls are used as a fuel in Bangladesh and in areas where parboiling is not practiced the rice hulls often remain unused and may in fact present a problem for disposal.

Rice hulls represent a renewable source of energy that becomes available at the same time that energy is required for the milling operation. It is appealing to look for ways in which the energy in the hulls could be used to power the rice mills thus reducing or eliminating the need for electricity or imported fuel.

Because 80% or more of the rice in Bangladesh is processed in rural areas this paper examines some systems that might be used to convert the energy in rice hulls to mechanical power for small rice mills.

2. THE POWER AVAILABLE FROM RICE HULLS

When rice hulls are burned completely, heat is produced to the extent of about 6,000 per pound of hulls. To put this in perspective;

a) Rice hulls have about 1/3 the energy content of petroleum based fuels which yield about 18,000 BTU per pound.

b) Rice hulls have about half the energy content of coal which yields about 12,000 BTU per pound.

c) Rice hulls make up approximately 20 percent of the weight of paddy (rough rice). The annual yield of paddy in Bangladesh is about 15 million tons of which 3 million tons will be hulls. In terms of energy this is equivalent to 3.6×10^{13} BTU or about 250 million imperial gallons of diesel oil.

d) A small rice huller with ½ ton per hour capacity requires about 10 horse power or less to power it. Such a mill will produce rice husk at the rate of 200 lbs per hour while it is running. This is equivalent to 1.2×10^{6} BTU per hour. If one takes 1 BTU as equivalent to 0.39×10^{-3} hp-hr this is equivalent to a potential 470 horse power (assuming 100% efficiency in converting heat to mechanical power).

e) Any system to convert the heat energy of the rice hulls to mechanical power will be considerably less than 100% efficient. Steam engines are notoriously inefficient in this respect with 10% thermal efficiency as a typical figure.

f) In our illustrative case it would be possible to use a system with as little as 2% efficiency and still have enough power to run the huller. Alternatively if a system achieved a thermal efficiency of 50% it would only be necessary to use 5% of the hulls with the balance available for other uses.

3. PRESENT USE OF RICE HULLS

In about 80 of the larger rice mills in Bangladesh the husk is used to fuel conventional boilers that drive steam engines to power the rice mill. Steam is also used to parboil the paddy. In general these mills use second-hand boilers and engines, however, there are not many boilers and engines available on the market any more.

In rural areas the husk is used as a fuel for parboiling and sometimes for cooking. A certain portion of the husk may be separated out along with the bran to be used as cattle feed.

4. METHODS FOR GENERATING POWER FROM RICE HULLS

a) Steam Power

As already stated, hulls are presently used in some mills to fire boilers and power the mill by means of steam engines. Steam engines and boilers can easily be made in any size but there are several problems that would have a bearing on the use of conventional steam engines in small mills. A steam engine, boiler and fittings will cost substantially more than a diesel engine of equivalent power. The boiler must be licensed, periodically checked and operated by a certified boiler operator. While this is not a particular problem for a large mill it would be difficult for numerous small mills in rural areas. A second problem is that scaling down the boiler and engine to suit the size of the small mill the efficiency which is already low will be further reduced and it may be that the husk alone might not have sufficient energy to operate the mill.

b) Producer Gas

When rice husk or other carbonaceous material is burned in an atmosphere of reduced oxygen along with the introduction of a little water, a combustible gas is produced (mainly hydrogen and carbon monoxide). This gas can be used to fuel an internal combustion engine. It would be technically feasible to convert a diesel engine in a rice mill to operate on this "producer gas" and use the rice husks to fuel the producer gas generator. Mills of this sort have operated in Italy and development is underway on this technology in several countries, however, the system has not been perfected. The complexity of operation would make this technology difficult to introduce in rural areas.

c) Pyrolysis

Pyrolysis is somewhat like producer gas generation except that gas is a minor product while oil and char form the bulk of the product. So far this is in the development stage. Again complexity of operation would pose a problem for a small rural mill.

d) Organic Rankine Cycle Engines

The conventional steam engine or turbine is a Rankine engine. Organic Cycle Rankine engines are similar to conventional steam engines and turbines except they use an organic fluid, frequently a refrigerant such as one of the freons, instead of water. These systems have been well developed for use in solar energy systems where operating temperatures are low.

An advantage of these systems is that they can be entirely sealed and because the working fluid is non-corrosive it should be possible to avoid any need for maintenance over periods of years.

In order to have a fully sealed system the engine could drive a generator with power drawn off the form of electricity.

e) Efficient Steam Rankine Cycle Engines

Work has been done to improve the efficiency of Rankine engines based on a steam cycle but retaining some of the features of the ORC engines so that they can be used to generate power from solar or waste heat. An advantage of the steam cycle is that the working fluid (water) is not susceptible to damage by high heat, also by operating at higher temperatures a higher efficiency can be obtained.

f) Stirling Engines

Stirling engines are heat engines which were first developed in the last century. Originally with efficiencies of only 2% they were displaced by petrol engines. Recently the advent of new materials and technology has permitted the development of engines with improved efficiencies. Presently free piston Stirling engines are available with greatly simplified construction and improved methods for sealing. Efficiencies of 12% are reported for experimental models of Stirling engine/generator combinations and they can be made in sizes ranging from a few watts to many kilowatts power output. As with the organic cycle Rankine engines this system can be sealed and largely maintained free.

5. DISCUSSIONS

a) Organic cycle Rankine and Stirling engines are appealing alternatives for powering small rice mills because of the possibility of operating as sealed and maintenance-free power generating units. The husk furnace however, would require attention on a regular basis.

b) The major constraints on practical application of organic cycle Rankine or Stirling engines to powering small rice mills is one of cost. Presently costs of these units are high because of low production levels and high labor costs in the developed countries. The power units could be made in developing countries with cheap skilled labor and with a large market prices might fall within an acceptable range.

c) If a heat to power conversion unit was produced that was financially within the reach of the small rice mills the potential market would be enormous. Accurate figures are not available for the number of small huller mills in Bangladesh but it is likely that there are over 10,000 in the country now and this represents only the first shift from manual to machine processing. In other countries there are hundreds of thousands of these small mills.

d) Presently available technology for Stirling engines is giving 12% thermal efficiency in converting heat to electricity. Organic cycle Rankine engines are presently yielding efficiencies of 20% and higher.

If a husk fired unit was developed that had 10% thermal efficiency then in the previously mentioned case of a ½ ton per hour mill the potential 470 hp would yield an actual 47 hp in the form of electrical power. Of this 47 hp the mill itself would require 10 hp. This would leave a balance of 37 hp for other purposes. If there was a pressing need for use of the hulls for traditional uses such as

cooking and parboiling then the hulls could be used for that, however, let us consider the possibility which would arise if the power unit was portable and could be moved to the field. It could then be used to power an irrigation pump for example. By operating our mill for one hour we get an excess of 37 hp-hr which would be about enough to operate a 5 hp irrigation pumps for an 8-hour day.

A problem with husk is its large bulk which makes transportation and storage a problem. In our hypothetical case it would take 160 pounds of husk to operate the irrigation pump for 8 hours. This would be equivalent to several headloads of bagged rice husks but because of the value of the irrigation and the short distances that would likely be involved this might not be much of an obstacle.

With power units of greater efficiency, less hulls would do more work so that transportation problems would be reduced.

e) Discussion has been confined to rice husk buth other fuels such as jute sticks could also be used if desired.

A N N E X C

USAID DIRECTOR PROJECT

APPROVAL

UNITED STATES GOVERNMENT

memorandum

DATE June 9, 1981

REPLY TO ATTN OF Ingrid T. Buxell, PRO

SUBJECT TAF/Rice Project Phasing, Cost and Design Criteria

TO Frank Kimball, DIR

Thru: Larry Crandall, PRO

Attached, as requested, is a table summarizing the three phases of the TAF/Rice Proposal according to cost, activities to be performed, and criteria for determining project continuity. The critical activities in each phase relate to the design, production and testing of a prototype (phase 1), four intermediate units (phase 2) and four pre-production units (phase 3). In addition, phases one and two have ancillary activities related to the availability and utilization of rice husks and the compatibility of alternative milling systems (there exist five in Bangladesh) with the Stirling Power Units. If, at the end of phase one, the prototype does not meet the criteria for proceeding to phase two, there will be certain costs, such as contractor forward funding, that will be deobligated.

It is requested that you indicate your approval/disapproval for this project by signing in the appropriate place below.

Approval Frank B. Kimball June 10, 1981
Frank B. Kimball

Disapproval _____
Frank B. Kimball

Attachment : a/s

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

OPTIONAL FORM NO. 10
(REV. 7-70)
GSA FPMR (41 CFR) 101-11.6
5010-112

GPO 1979 0-281-187 P.O. 4304

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TAF/RICE
THREE PHASE PROJECT COST AND DESIGN CRITERIA

Phase I	Cost	Task/Activities	GO/NO-GO Criteria
(1-12 mos.)	$477,709*	A. Development and production of a Stirling Power Unit proto-type at Sunpower, Inc. Athens, Ohio. B. Ongoing assessment of rice husk availability and its utilization.	A. Stirling Power Unit Proto-type : 1. The engine works efficiently with rice husks as the fuel. 2. The engine produces the specified power necessary for operating a small rural rice mill (No. 4 huller). 3. The design is deemed feasible for extant Bangladesh manufacturing capability in terms of the processes and manufacturing technologies involved. 4. The production cost is reasonable and competitive with fossil-based fuel engines in Bangladesh. B. Projections can be established for the availability of rice husks for commercial production of the engine
Phase II 13-24 mos.	$244,745	A. Fabrication and testing of four intermediate Stirling Power Units at Kumudini Welfare Trust in Bangladesh. B. Determination of future Stirling Power Unit applicability in alternative milling systems.	A. The Intermediate Stirling Power Units : 1. Are locally manufacturable, provide cost estimates for preproduction models, and are operable under field conditions. 2. Comparative advantages in terms of real energy costs are maintained. B. Stirling Power Units are shown to be compatible with milling systems.
Phase III 25-36 mos.	$203,263	A. Designing manufacturing patterns for mass-production (jiggs and fittings) B. Production of four preproduction units by existing local manufacturers (under sub-contract). C. Evaluation (testing) of preproduction units. D. Preparation of Final Report : Design details and test results.	A-C. Production Techniques are developed and are operable. D. Manual for producing Stirling Power Units on mass-scale by standard local manufacturers.

* If activity does not meet "GO" criteria, certain costs (e.g. consultant contract forward funding) will be deobligated.

Prepared by USAID : 6/9/81