**TOTAL ENERGY RECOVERY SYSTEM
FOR AGRIBUSINESS**

FINAL REPORT

**Sam F. Fogleman
Leonard A. Fisher
Allan R. Black
Dev P. Singh**

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Date Published -- May 1977

UNDER CONTRACT EY-76-C-03-1327

**PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
DIVISION OF GEOTHERMAL ENERGY**

**INTERNATIONAL ENGINEERING COMPANY, INC.
220 MONTGOMERY STREET
SAN FRANCISCO, CALIFORNIA 94104**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EB

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
1.1 General	
1.2 Background	
1.3 Objective	
1.4 Scope of Work	
1.5 Limitations of the Study	
1.6 Organization of the Report	
2. GREENHOUSE TOMATOES AND CUCUMBERS	3
2.1 Introduction	
2.2 Products Considered	
2.3 Tomatoes	
2.4 Cucumbers	
2.5 Greenhouses and Equipment	
2.6 Yields and Returns	
3. FISH FARMING	10
3.1 Introduction	
3.2 Selection Considerations	
3.3 Giant Prawn Environmental Requirements	
3.4 The Ponds	
3.5 Water Hyacinth	
3.6 Yields and Returns	
4. MUSHROOM CULTURE	15
4.1 Introduction	
4.2 Selection Considerations	
4.3 Cultural and Environmental Requirements	
4.4 Mushroom Houses and Equipment	
4.5 Yields and Returns	
5. BIOGAS GENERATION	20
5.1 Introduction	
5.2 The Role of Biomass Digestion in TERSA	
5.3 Principles of Operation	
5.4 Equipment Design	
5.5 Inputs and Outputs	
6. INTEGRATION METHODOLOGY	26
6.1 Introduction	
6.2 Temperature Cascade Considerations	
6.3 Nutrient Cycling Considerations	
6.4 Space Considerations	
6.5 Economic Considerations	
7. HYDROTHERMAL FLUIDS AND HEAT EXCHANGER SELECTION	29
7.1 Introduction	
7.2 Hydrothermal Fluids	
7.3 Scaling	
7.4 Corrosion	
7.5 Heat Requirements	
7.6 Criteria for Heat Exchanger Selection	
7.7 Heat Exchanger Selection	

8. THE SYSTEM	39
8.1 Introduction	
8.2 System Description	
8.3 System Site Plan	
8.4 Operation and Maintenance	
8.5 System Economics	
9. CONCLUSIONS AND RECOMMENDATIONS	48
REFERENCES	50
APPENDIX	60

1. INTRODUCTION

1.1 GENERAL

International Engineering Company, Inc., (IECO) has performed this engineering and economic study for the United States Energy Research and Development Administration under Contract Number EY-76-C-03-1327 to evaluate the application of geothermal heat from hydrothermal sources for agribusiness production of greenhouse and other crops, fish farming, and ancillary services such as biogas generation.

1.2 BACKGROUND

Improvements in agribusiness biologic cycle efficiencies are attainable in controlled environments which utilize energy recovered from geothermal resources that are not suitable for power production. Furthermore, by combining greenhouse crops, mushroom culture, fish farming and biogas generation into an integrated biologic system, the waste or by-products of each subsystem cycle can be recovered to service input needs of companion cycles.

1.3 OBJECTIVE OF THE STUDY

The objective of this study is to evaluate the costs and viability of combined thermodynamic and biologic cycles in a system known as the Total Energy Recovery System for Agribusiness (TERSA).

1.4 SCOPE OF WORK

This study includes: preparation of detailed conceptual design for the construction of TERSA as described hereinafter; specification of principles of operation of TERSA; identification of existing commercial equipment suitable for pilot plant application; estimation of system capital, maintenance, and operating costs; and calculation of the rate of return on investment for the proposed system based on approximate product market values. Unique environmental and educational values resulting from the systems engineering approach to resources are also presented.

1.5 LIMITATIONS OF THE STUDY

The Total Energy Recovery System for Agribusiness is a conceptual design. However, most individual cycles and equipment components have been proven in actual similar service.

Detailed design and integrated system testing are required before such a system can actually be employed. The alternatives considered were such that TERSA is realistic

within the current state-of-the-art. While sufficient data were available for this conceptual phase, experimental determination of heat exchanger performance with the specific hydrothermal fluid to be used will be a necessity for a finalized TERSA design because empirical data for this type of application are limited.

Although some nutrient cycling experiments can be carried out on a laboratory scale, great care must be exercised to utilize proven practices in the agribusiness subsystems of the Total Energy Recovery System for Agribusiness.

1.6 ORGANIZATION OF THE REPORT

TERSA subsystem activities and economics are discussed separately prior to discussion of the integrated system. Should the reader be interested in the roles of these subsystems in the total system during these individual discussions, reference should be made to Figures 8-1 and 8-2 and Tables 8-1 through 8-4.

2. GREENHOUSE TOMATOES AND CUCUMBERS

2.1 INTRODUCTION

Greenhousing is the raising of plants in a controlled environment to enhance yields. The greenhouse effect results from trapping of solar radiation and heat by using glass, plastic film or fiberglass as environmental control surfaces to enclose a growing area. (Ref. 125).

In addition to solar heating, other controllable heating and/or cooling must be applied to maintain temperatures for optimum plant growth. Environmental elements besides temperature that must be optimal or at least non-limiting in order to get the best yield of saleable product during the desired marketing period are: level of plant nutrients in the growing media; carbon dioxide content in the air; humidity; soil or nutrient media aeration; plant spacing; plant variety; disease control; sunlight or artificial light supplement; and cultural practices such as pruning, plant training and pollination.

2.2 AGRICULTURAL PRODUCT CONSIDERATIONS

The agricultural products considered for TERSA greenhousing were those known to be commercially successful greenhouse crops: tomatoes, European cucumbers, lettuce, cut flowers, and potted plants. Their approximate March 1977 wholesale prices (Ref. 132 unless otherwise indicated) are listed below:

- greenhouse tomatoes \$0.45-0.63/pound (Ref. 72)
 (winter prices)
- European cucumbers #1 \$0.45-0.52/pound
 (California hothouse grown)
- iceberg lettuce \$0.13/pound
- romaine lettuce \$0.15-0.16/pound
- butter lettuce \$0.19-0.21/pound
- potted poinsettia \$1.00/six inch pot
- cut carnations \$0.05/flower (Ref. 26)

Hydroponically grown tomatoes and lettuce were considered as each crop has good income potential. Hydroponic greenhousing involves circulating nutrients through an artificial media such as sand or gravel instead of using soil as the growing media. Hydroponically grown tomatoes utilizing geothermal water for the nutrient solution as well as for greenhouse heating are reported to be in production

at Wendell Hot Springs (Hobo Wells) near Susanville, California. (Ref. 114). However, there is the significant risk that a malfunction of the equipment, one wrong formulation of nutrient solution, or lack of aeration can cause a total loss of the crop. Therefore, soil grown greenhouse procedures were selected for the Total Energy Recovery System for Agribusiness.

The growing of greenhouse flowers was considered, but due to the uncertainty of profitable returns in competition with the relatively cheaply grown imported flowers currently influencing the market, the large number of greenhouse air changes required for flower growth with resulting heat losses, the lack of current detailed costs of production, and relatively high disease potentials, the geothermally heated greenhouse production of flowers was not pursued in this study. Potted plant production faces similar environmental problems and was also not pursued. This is not to say that, with more in-depth analyses and secured marketing at a particular site, flower production by itself or in combination with other plants would not be profitable and, in fact, TERSA greenhouse facilities can be adapted to alternate crops with minor cycle modifications.

Tomatoes and European cucumbers are compatible as alternating greenhouse crops and employ the same cultural techniques and facilities. Tomatoes can be grown when lower priced field grown tomatoes are not available; cucumbers will be grown during the bulk of the remaining portion of the year. Based on their documented greenhouse profitability and the other factors discussed, tomatoes and cucumbers were selected for TERSA greenhousing.

2.3 TOMATOES

"Tomatoes are the most widely grown greenhouse crop in the world. Two good reasons for this are the steady high consumer demand for tomato fruit and the high yielding capability of the plant." (Ref. 77).

Greenhouse tomatoes are best grown between 75°F and 80°F during the day and above 60°F at night. The optimum relative humidity is seventy percent for pollination, fruit set, and fruit development and should never exceed eighty-five percent.

Tomato plants are spaced to provide three to four square feet per plant and each is trained to a single stem. All lateral branches are removed and the plants are supported by attaching them to vertical strings suspended from overhead horizontal wires. The spacing and pruning allow for proper air circulation, high density planting, and maximizing of the entire volume of the greenhouse for leaf interception of sunlight for photosynthesis. The tomato plant is lowered as required for ease of picking and pollination is assisted by daily vibration of newly opened flowers. (Ref. 70).

Tomatoes require fertile soils. Elements for proper plant growth should be available through the soil, added through fertilizer applied directly to the soil, or injected through the irrigation system. The drip or trickle irrigation method selected for TERSA minimizes water consumption while metering nutrients to the plants. Experience at a specific site with the selected crop varieties, soil, growing season, counsel from the Agriculture Extension Service, and leaf analysis will determine the best procedure and amounts of nutrients to add. For this study average values of nutrients were used as the basis for costing. (Ref. 77).

Water application rates generally vary from three to over ten acre-feet per acre per year for the canopy area of the growing plants. In actuality tensiometers can be placed in the root zone to adjust the irrigation applications to soil moisture. For this study a value of five acre-feet per acre per season was used as the representative tomato value. (Ref. 77).

Carbon dioxide enrichment inside of the greenhouse area is also considered in TERSA. Where greenhouse vents have to be closed for prolonged daytime periods in cold weather in order to conserve heat, tomato yields have been increased twenty to thirty percent with carbon dioxide enrichment; 1,000 to 1,500 ppm carbon dioxide is thought to be the optimum level. (Ref. 74).

The University of California mentions three best candidate tomato varieties for greenhouse production: "Tropic", "Floradel" and "Michigan-Ohio Hybrid". (Ref. 74). Actual selection would be determined by the TERSA site.

2.4 CUCUMBERS

Greenhouse cucumbers should be grown at daytime temperatures between 80°F and 85°F and nighttime temperatures between 65°F and 75°F. Relative humidity should be kept below eighty-five percent.

Plant spacing for greenhouse grown cucumbers in Europe, Canada and the eastern United States varies from six to eight square feet per plant. Excellent yields in California have been obtained with these spacings, although some growers also get good results with only three square feet per plant. Like the tomato, each cucumber plant is supported by a vertical string connected to a horizontal wire that is suspended over the length of the greenhouse and the plant rows. This overhead support wire is usually elevated seven or eight feet above the ground. Cucumber pruning and training techniques are employed to obtain good air circulation, optimum exposed leaf surface and maximum yields. (Ref. 73).

All fertilizer, except a continuous supply of nitrogen, should be incorporated in the soil beds before

transplanting. Nitrogen is metered to the plants through the trickle irrigation system beginning a few weeks after transplant to the greenhouse.

Experience, soil analysis, leaf analysis and plant response will dictate the proper dosage of fertilizer nutrients. Acid soils and heavy textured soils will require liming. In continuous alternate cropping of tomatoes and cucumbers it is advisable to test the soil for carryover nutrients from the preceding crop.

Cucumbers should have an abundant supply of water for maximum production. Properly managed drip irrigation can keep the soil at near field capacity and maintain good aeration without soil saturation. Tensiometers placed in the root zone will assist in setting the length of time the drip irrigation system will operate each day.

The cucumbers used in the TERSA greenhouses are of the European variety and it is necessary to prevent pollination because seed development causes fruit distortion. All doors and vents are screened as required to prevent pollination with American type cucumbers grown outside. The European greenhouse cucumbers commonly grown in California are "Toska 70" and "Fertila". (Ref. 73).

2.5 GREENHOUSES AND EQUIPMENT

The TERSA greenhouses are thirty feet wide by one hundred feet long (3,000 square feet) and have walls and roof of Tedlar coated fiberglass of twenty year life expectancy. One-half of the heating requirement is accomplished by circulating air past two coils heated by the TERSA clean water loop and passing the heated air through two perforated convection tubes running the length of each greenhouse; the other fifty percent of heating comes from pipes carrying heated water embedded in the perimeter concrete. Humidity is controlled during heating periods only by humidistat operated motorized louvers. (See Figure 2-1). The circulation fans remain on at all times except during later portions of cooling operations. When a cooling requirement is sensed by temperature controls, the following is the sequence of events: (1) the motorized louver servicing the Cel Dek Evaporative Cooler depicted in Figure 2-1 opens and one exhaust fan begins operation as its louver also automatically opens; (2) if further cooling is required automatic operation of water flow in the cooling unit and the second exhaust fan/louver are initiated and the circulation fans are stopped; (3) in extreme cases the third exhaust fan/louver is energized. The Cel Dek Evaporative Cooler utilizes a treated impermeable cardboard mass which permits water trickle during operation and does not require replacement; previously used evaporative pads require yearly replacement.

Figure 2-1. Typical TERSA Greenhouse

Irrigation, nutrient, and chemical requirements are controlled on bases previously discussed. All controls, except thermostats, are of solid state construction. Illumination is provided for nighttime personnel access. (Ref. 113).

2.6 YIELDS AND RETURNS

In order to maximize the use of greenhouses and associated equipment while attempting to optimize income, alternate cropping of tomatoes and cucumbers was chosen for the Total Energy Recovery System for Agribusiness. Such continuous usage is particularly important in environmentally controlled greenhouse production where fixed costs are relatively high. Tomato prices are highest from December through May, when California is not producing field grown tomatoes and the supply from Mexico is of lesser quality. From June through November, field production of tomatoes in California suppresses the premium prices received by greenhouse grown tomatoes. Additional considerations in not growing tomatoes throughout the year are typically high summertime temperatures and solar radiation which adversely effect greenhouse tomato quality. (Ref. 77).

European type greenhouse cucumbers are not only tolerant of summer sunlight and higher summer greenhouse temperatures, but also command good market price during this period. In addition greenhouse cucumbers and tomatoes continuously produce new flowers and fruit so their cropping period is somewhat flexible and, to maximize returns and take advantage of this flexibility, the TERSA greenhouse evaluation is based on growing tomatoes for six months, followed by a four month production period of cucumbers.

The reported yield of greenhouse tomatoes for a six month crop period shows considerable variance. The University of California Extension reports figures which indicate typical productions of 2,750 to 5,000 pounds of tomatoes per 1,000 feet of greenhouse per half year crop. (Ref. 75, 77). The Hobo Springs geothermally heated hydroponic greenhouses report yields which convert to 5,400 to 5,850 pounds per six months per 1,000 square feet of greenhouse with a target figure of 6,000 pounds. (Ref. 114). On these bases 4,000 to 5,000 pounds of tomatoes per six month crop per 1,000 square feet appeared a reasonable range to use for TERSA and the tomato yield for six months was assumed to be 4,500 pounds per 1,000 square feet of TERSA greenhouse.

European type greenhouse cucumbers are harvested for eight to ten weeks during a four month cropping period with reported reasonable production yielding 3,200 to 4,500 pounds per 1,000 square feet of greenhouse per four month crop. (Ref. 73). Consequently, 4,000 pounds per 1,000 square feet was selected as the estimated crop for TERSA.

TERSA has 9,000 square feet under greenhouse cover resulting in a projected annual yield of 40,500 pounds for the winter season tomato crop and 36,000 pounds for the summer season cucumber crop based on the preceding. Using conservative first quarter 1977 wholesale selling prices of \$0.50 per pound for winter greenhouse tomatoes and \$0.45 per pound for European hothouse cucumbers, the greenhouse products of the Total Energy Recovery System for Agribusiness yield an annual estimated income of \$36,450.

3. FISH FARMING

3.1 INTRODUCTION

Aquaculture is the cultivation and husbandry of freshwater and marine organisms under levels of control on the aquatic growth environment which are functions of the intensity of the aquacultural operation.

Fish farming is that portion of aquaculture which involves the rearing and harvesting of aquatic animals. Among farmable species are: common carp, Chinese carp, Indian carp, buffalo fish, paddle fish, catfish, pikes, perches, black bass, sunfish, tilapia, frogs, mullet, milkfish, eels, salmon, salmonids, smelt, sturgeon, shad, striped bass, shrimp, lobster, crayfish, crabs, oysters, clams, scallops, mussels and abalone. (Ref. 18, 62, 63).

3.2 SELECTION CONSIDERATIONS

The main geothermal resources in the continental United States are inland in the western part of the country, away from the ocean. In view of this fact and the potential of salt water contamination to the groundwater and streams resulting from saline growing ponds it was decided to focus this study on freshwater aquaculture.

Some freshwater species acceptable to the American market and their March 1977 wholesale prices are (Ref. 132 unless otherwise indicated):

- large Icelandic prawns \$7.80-7.90/pound
(12-15 per pound)
- large Singapore prawns \$6.25-6.30/pound
(12-15 per pound)
- large Mexican prawns \$5.80/pound
(10 per pound)
- trout \$1.65-1.70/pound
(Idaho, random weight)
- catfish \$1.10-1.30/pound (Ref. 104)
- buffalo fish \$0.85-1.00/pound (Ref. 104)
- Louisiana bass \$0.85-1.00/pound (Ref. 104)

Prawns and catfish were considered suitable selections for this study as both can be intensely cultured, grow optimally at elevated temperatures (unlike most other species popular in the U.S.), and can be readily marketed in the United States. The giant Malaysian prawn, Macrobrachium

rosenbergii, was selected as the fish farming crop of the Total Energy Recovery System for Agribusiness project on the basis of its very high market value, proven commercial farming, and excellent potential for elevated temperature aquaculture.

These giant prawns grow best at temperatures of 82-88°F (28-31°C), temperatures which are rarely encountered for continuous duration in nature. Macrobrachium rosenbergii: grows rapidly to harvest size of ten per pound; reproduces well in captivity with recently developed techniques; is relatively disease resistant, hardy, and adaptable to culture conditions; is omnivorous - will eat plant or animal material; has a good rate of conversion of feed to body tissue; has a high percentage of meat to body weight; and the meat has high taste quality and texture. (Ref. 37, 48, 49, 50, 115).

In Hawaii there were approximately thirty acres of farming of these giant prawns underway in 1976. (Ref. 37, 115). In addition this state has the following ongoing research activities relating to the giant prawn: (1) spawning in captivity; (2) larval rearing; (3) juvenile to market size rearing; (4) behavioral research; (5) nutritional requirements and formulation; (6) disease in rearing schemes; (7) genetic selection experiments; (8) facilities engineering; and (9) production economics and marketing. Other research is progressing at the Hydrobiology Laboratory of the University of California and the rearing of this species has been well documented. (Ref. 37, 83).

3.3 GIANT PRAWN NUTRITIONAL REQUIREMENTS

The giant prawn is omnivorous. The present commercial method of feeding them in Hawaii is to provide chicken broiler starter (chicken feed) at the edge of the earthen rearing ponds and adjust each day's feeding according to the previous day's consumption. The unused chicken feed helps fertilize the pond which will, in turn, provide a natural supply of algae and zooplankton. (Ref. 115).

The Total Energy Recovery System for Agribusiness approach adds several compatible elements to the prawn ponds. The ponds will contain some tilapia fish to help clean up the detritus on the bottom of the pond. The tilapia will be harvested periodically, cooked, chopped, screened and fed to the prawns as a meat supplement. Water hyacinth, a free floating fast growing plant, will provide cover and an additional food supply for the shrimp. Another source of food in the TERSA nutrient cycle would be the composted slurry fertilizer exiting from the biogas digester. (See Figure 5-1. TERSA Nutrient Cycling.)

As the cost of feed is the most important operating cost item for large scale prawn rearing (Ref. 115), the advantage of TERSA's integrated systems in cost saving can be very

significant in final product cost analysis. Furthermore, chicken broiler starter is not optimum in nutritional value or cost-effectiveness (Ref. 115) and the Hawaiian Institute of Marine Biology of the University of Hawaii and the Hydrobiology Laboratory at the University of California are both researching the nutrition, food requirements and food formulation of the giant Malaysian prawn.

Cannibalism has been mentioned as a possible problem in freshwater prawn rearing. Although this is not thought to be a problem in the Hawaiian giant prawn industry, providing feed slightly in excess of what can be consumed mitigates the possibility of sufficiently hungry prawns resorting to cannibalism. (Ref. 18).

Other factors that limit production are: (a) competition among the large mature males ("bulls") for territory; and (b) susceptibility of small, newly molted (soft shelled) prawns to accidental damage resulting from being stepped on by larger prawns in the densely populated ponds. (Ref. 48).

Some solutions to these problems provided by aspects of proper pond management are: control of stocking density; frequent restocking; selective harvesting for removal of larger animals as they reach market size; and matching food availability to requirements. Furthermore, feeding of ten percent animal protein or fish flesh reduces cannibalism (Ref. 48) - this is achieved in TERSA by feeding the prawns cooked and chopped tilapia harvested from the ponds.

The use of barriers to larger prawns also assists in control of cannibalism and damage to molting prawns. This is accomplished in the TERSA ponds by the placement of mesh along the heating pipes discussed in the next section and may be augmented by the erection of shelters for the smaller prawns. In addition the water hyacinth present in the ponds provides sheltering habitat.

It should be noted that a recent experiment in New Jersey for raising Macrobrachium rosenbergii using powerplant thermal effluent demonstrated a survival rate of over ninety percent. (Ref. 12).

3.4 THE PONDS

The use of earthen ponds for fish farming is reported as far back in history as the fifth century B.C. The pond muds provide fertility inputs into the biological cycles of algae, snails, worms, insect larvae, tadpoles, mosquito fish, tilapia, giant prawns, and water hyacinth. Earthen ponds were selected over other prawn rearing systems on the separate recommendations of Dr. Takuji Fujimura, Chief of the Anuenue Fisheries Research Center in Hawaii, and Dr. Allen W. Knight of the Hydrobiology Laboratory of the University of California at Davis, both recognized experts

in giant prawn (Macrobrachium rosenbergii) culture and research.

TERSA prawn ponds are designed in accordance with typical layouts as used in commercial practice and provided by the State of Hawaii Department of Land and Natural Resources. There are six ponds, each slightly more than 200 feet long by 100 feet wide, amounting to a half acre each in surface area. Water is maintained in the ponds to a depth of three feet by berms four feet in height which sloped at three units horizontal to one vertical. There is sufficient crest width on the berms to provide access for motorized vehicles for harvesting and other required activities.

Each pond is heated by approximately 600 feet of copper pipe traversing the length of the pond three times. This pipe is supported along its length at a height one foot above the pond bottom and in turn supports netting also attached to the bottom which is of size sufficient to allow passage to small prawns, but restricts passage of prawns near harvestable size. This method of size segregation not only provides a means of protecting small prawns from damage by those larger, but also divides the pond into four smaller separate areas from which mature prawns cannot escape harvest by seining.

3.5 WATER HYACINTH

Water hyacinth (Eichhornia crassipes) is a vascular free-floating aquatic plant. Its seeds will germinate on floating debris or on an organic bank or bottom. This plant, introduced in the United States in 1884, is considered a serious pest in most of the subtropical and tropical areas of the world as it clogs waterways with its abundant growth. (Ref. 126). Until recent times, it was thought to have few redeeming qualities.

Water hyacinth is often used in fish farming. (Ref. 62). TERSA grows this plant in the heated prawn ponds to provide shelter and food for the prawns and scavenger fish. The Total Energy Recovery System for Agribusiness takes advantage of the extremely rapid biomass production rate of water hyacinth by harvesting it with floating booms and a tractor for utilization of slightly over three-quarters of the yield as a portion of mushroom growing media and the remainder for biogas/compost production as is discussed in following chapters. TERSA is conservatively assumed to produce hyacinth over only one half of its three acres of ponds at the reported rate of 529 pounds of dried matter per acre per day, yielding 794 pounds on an average daily basis. (Ref. 130).

Recent and ongoing research at the National Space Technology Laboratories has revealed an additional benefit of water hyacinth: it is proficient in removing pollutants from the water it inhabits. (Ref. 129, 130). The plant has proven

effective in removing phenols, cadmium, nickel, lead, mercury, photographic pollutants, silver, cobalt, strontium, sewage solids and pesticides.

The management of water hyacinth, in order to capitalize on its desirable characteristics and negate its spread as a noxious water weed, is very important. Methods of potential control include: covering the growing ponds; operating in an isolated area or one without waterways or dams; and pruning of the plant to prevent flowering. In that water hyacinths grow well in warm water, it is possible that no water hyacinth growth will occur in areas where the waterways and reservoirs are cold. Further inquiry as to precautions being taken by industry for their water hyacinth water clean-up ponds and investigation of the literature for water hyacinth control measures is in order.

3.6 YIELDS AND RETURNS

Giant Malaysian prawn yields appear to be a function of temperature, assuming that nutritional requirements are met, with maximum feeding and resultant growth occurring near 88°F (31°C). (Ref. 59).

In the Hawaiian semi-tropical climate 3,000 to 3,500 pounds of prawns per acre can be grown in an eight month growing season with no pond temperature control. (Ref. 115). The TERSA study assumes that, with ponds hydrothermally heated throughout the year at or near the optimum growth temperature and a year long production operation involving continuous restocking following size selective harvesting, a minimum annual production of 4,500 pounds of prawns per acre can be attained. This production level is quite conservative compared to the apparent upper annual pond prawn production limit of 8,000 pounds per acre estimated by Dr. Knight of the University of California Hydrobiology Laboratory.

TERSA grown prawns are conservatively assumed to sell for \$4.00 per pound (wholesale) when fresh. The estimate for annual TERSA prawn farming income, based on the foregoing assumptions, is \$54,000.

4. MUSHROOM CULTURE

4.1 INTRODUCTION

Mushroom culture is the production of edible fungi under controlled conditions.

The most common edible fungi naturally found in the United States is the Agaricus campestris. A horticultural adaptation of this species, Agaricus bisporus, has been developed as the commercially cultivated mushroom of this country. Fungi, due to the absence of chlorophyll, cannot carry on photosynthesis and must depend upon organic matter for nutritional requirements. (Ref. 80, 88, 117).

The United States produced over 142 million pounds of mushrooms for the fresh sales market and almost 168 million additional pounds for processing during the 1974-1976 reporting period. This production, amounting to almost 155,000 tons in 1974-1976, is projected by the mushroom industry to reach 272,000 tons in 1982-1984. (Ref. 80).

4.2 SELECTION CONSIDERATIONS

Mushroom culture was selected as a subsystem for the Total Energy Recovery System for Agribusiness instead of row crops as originally proposed. (Ref. 68). This selection was based on the following considerations:

- high price per pound
- intensive culture consistent with other subsystem activities
- grown in a controlled environment requiring both heating and cooling which can be provided by TERSA
- the culture media plays a vital role in TERSA nutrient cycling, providing compost, biogas, and fertilizer after service for mushroom growing
- water hyacinth from the prawn ponds may be used for one-third of the growing media.

4.3 CULTURAL AND ENVIRONMENTAL REQUIREMENTS

Mushrooms reproduce by means of minute spores which, given a favorable environment, produce threadlike masses called mycelium. The mycelium, in turn, produce edible mushrooms if certain environmental and cultural requirements are met. Commercial laboratories produce pure cultures of mycelium, called "spawn", to assist the mushroom grower in initiating propagation.

The spawn is grown on prepared compost which may be made from chicken or other manure and horse bedding straw or may be "synthetic". Synthetic compost can be made from a number of materials, a combination of hay, chopped corn cobs, and chemical additives being the most popular. (Ref. 80, 88, 112). Furthermore, synthetic compost may be combined with manure for mushroom growing purposes.

The literature (Ref. 57, 112) and some discussions with technical personnel indicate that water hyacinth may be used as a portion of the compost material. Further investigation of the process details needs to be pursued. For purposes of the Total Energy Recovery System for Agribusiness project, it has been conservatively assumed that the mushroom compost will consist of two-thirds hay, manure, and chemical additives, and one-third water hyacinth.

Mushroom compost must go through a conditioning process which is performed on the outdoor cement composting pad adjacent to the mushroom houses. The purpose of this conditioning is to make the compost uniform, well watered, of the proper nutrient level and properly organically decomposed by aerobic microorganisms. The conditioning process takes about seven to twelve days and involves wetting, aeration, and mixing. (Ref. 81, 88).

Following conditioning, the next phase of the mushroom growing process, pasteurization, takes place after all the mushroom house beds are filled with about six inches of conditioned compost. Following this filling, doors and ventilation openings are closed and the temperature in the beds is allowed to rise to 134-140°F. This heat is generated from the prepared compost and may be assisted by introduction of heat such as that available from geothermal fluids. It usually takes three days to reach this temperature and then the beds are maintained at this temperature for about a day, until all odor of ammonia has left the compost. The mushroom house is then ventilated and the temperature in the compost beds is allowed to drop to 74-80°F. This completes the pasteurization process. (Ref. 117).

The next operation is called spawning and involves introduction of the (usually) commercially produced spawn to the composted beds. The spawn is either broadcast over the bed surfaces ("grain" spawn) or planted two inches deep ("manure" spawn). The compost is kept moist and a temperature of 72 to 75°F is maintained during the spawning period. The grain spawn takes ten to fourteen days for the mycelium to grow throughout the compost. Manure spawn is slower and requires three to four weeks for spawning.

"Casing" follows spawning. Mycelium will not develop into the fruiting stage and produce mushrooms unless a thin layer of casing soil has been spread over the surface of the spawned beds. This casing soil may be either a loam or peat

or a mixture. The casing soil is sterilized with either heat or chemicals to destroy nematodes and soil diseases and is treated, if required, for neutrality in pH. A layer of about one inch of casing soil is placed over the beds and is kept moist with very light waterings until mushrooms begin to form. (Ref. 117).

Three to four weeks after casing, the mushrooms will begin to break through the casing soil. The temperature is then lowered to 60°F to improve mushroom growth and discourage diseases and insects. This lowering often requires cooling of the mushroom house.

Mushrooms develop in sudden outbreaks called "flushes" or "breaks" at about weekly intervals. The greatest production occurs during the first two breaks, with three to five additional breaks occurring over two to three months, depending upon the temperature.

Water is sprinkled on the surface of the bed at the beginning of each break and the humidity of the air in the mushroom house is maintained at seventy to eighty percent to prevent the mushroom caps from drying out. (Ref. 118).

4.4 MUSHROOM HOUSES AND EQUIPMENT

The TERSA mushroom houses are constructed with cinder or concrete block walls and consist of three so-called "standard single" houses sixty-eight feet long and twenty feet wide. A typical single house is illustrated in Figure 4-1. The single house contains two tiers of beds, six beds high and sixty feet long, with alleys around the tiers. The beds are between five and six feet wide, giving a total of 4,000 square feet of bedding space per single house, or 12,000 square feet total for TERSA. This standard arrangement allows for proper air flow, humidity, heating efficiency, filling, harvesting, and cleaning. (Ref. 80, 88, 117).

The mushroom house floor is sloped slightly to allow for drainage and a catwalk is provided at the level of the fourth bed to facilitate handling associated with the upper beds. The bed boards are made of decay resistant wood, preferably redwood, cypress, or cedar, and they can be removed as required to aid in filling and removing compost. The bottom bed is six inches off the floor and there are eighteen inches of working and air circulation space between the six inch deep beds.

The heat requirements of the mushroom houses are met by exposed piping along the walls carrying clean heated water. (Ref. 88). Ventilation is accomplished by the ridge type system shown in Figure 4-1. Cooling is carried out by evaporative methods when humidity control requirements permit, and at other times by use of small commercial air conditioning units.

Figure 4-1. Typical TERSA Mushroom House

4.5 YIELDS AND RETURNS

The U. S. average mushroom yield as of 1974-1976 was over 2.7 pounds per crop per square foot of bedding space, although much higher yields per square foot may be obtained with good management. (Ref. 80).

On an average production basis of 2.7 pounds of mushrooms per square foot of bedding space per crop and two and one-half crops per year (Ref. 16) 81,000 pounds of mushrooms would be produced annually by this TERSA subsystem. From the current wholesale price range of \$0.75 to \$0.85 per pound for medium sized fresh mushrooms (Ref. 80, 132), \$0.75 was selected as a conservative figure.

The mushroom culture yield, then, results in an estimated minimum gross annual income of \$60,750.

5. BIOGAS GENERATION

5.1 INTRODUCTION

A key element in the effort to make the Total Energy Recovery System for Agribusiness as self-sustaining as practicable in energy and fertilizer requirements is the biogas generation subsystem. Geothermal heat is used to promote elevated temperature anaerobic (taking place in the absence of oxygen) bacterial digestive action of organic material in enclosed containers.

In Mainland China low energy biogas units are reported in over 50,000 installations for producing methane and a sterilized organic compost from inputs of agricultural and animal wastes and water (Ref. 119). Biogas units are not uncommon in rural areas of India (Ref. 8) and are well suited to the rural type of agribusiness system envisioned in TERSA.

5.2 THE ROLE OF BIOMASS DIGESTION IN TERSA

As can be seen from the TERSA Nutrient Cycle (Figure 5-1), the biomass digestion process is central to nutrient recycling. The process provides fertilizer/compost inputs to all other agribusiness aspects of the Total Energy Recovery System for Agribusiness.

The inputs to the biogas units (as shown in Figure 5-1) are: water hyacinths from the prawn ponds; entrails and other remainders from the prawn and scavenger fish harvesting operations that are not reused directly as prawn nutrient; organic surplus from the greenhouse and mushroom crops; spent mushroom growing media; and any organic refuse which may occur or be accumulated at the TERSA site.

These inputs are decomposed in the biomass digesters under heat and pressure and the resulting biogas is burned in engine-generator sets to produce electricity for use as required by subsystem components. The organic compost that remains from this processing is utilized as planting mulch and fertilizer for the agricultural activities and as a fertilizer to promote best growing conditions for the prawn ponds. It is possible that the portion of the biomass compost that is not recycled may be sold commercially; however, this economic benefit is not included in the TERSA economic analysis.

It should be noted that the waste heat from the biogas powered engine-generator sets may be used for heating the circulating TERSA clean water.

INTERNATIONAL ENGINEERING COMPANY, INC.			
DESIGNED <u>IECO</u>	CHECKED	APPROVED <u>[Signature]</u>	
DRAWN <u>HL</u>	INSPECT <u>TH</u>	RECOMMENDED <u>[Signature]</u>	
IECO 220 MONTGOMERY STREET SAN FRANCISCO CALIFORNIA 94104		DATE <u>MAY 1977</u> DRAWING NO.	

Figure 5-1. TERSA Nutrient Cycle

5.3 PRINCIPLES OF OPERATION

The decomposition of organic matter in the absence of oxygen is called anaerobic fermentation and is the basis of biogas production. Anaerobic fermentation of organic products results in methane, carbon dioxide, hydrogen, traces of other gases, and the production of some heat. The residue remaining is hygienic, rich in nutrients, and high in nitrogen. Weed seeds and potentially damaging germs are killed by the absence of oxygen during the fermentation process, rather than by the significantly higher heat generated by the aerobic process. (Ref. 118). The raw organic waste is digested by various (anaerobic) bacteria within it in what may be viewed as two stages consisting of digestion by bacteria whose products support secondary bacteria which produce methane.

The efficiency and rate of anaerobic fermentation are affected by temperature, relative concentration of carbon and nitrogen, pH, and solids concentration, as is explained by the following.

The biogas producing digestive activities are optimal in two temperature ranges: 85°-105°F and 120°-140°F, although digestion will occur from freezing to 156°F. Fermentation, however, is less stable in the higher of these two ranges (Ref. 118) and, consequently, the TERSA biogas units are maintained in the lower optimal range.

The bacteria of the anaerobic fermentation process require thirty to thirty-five times more carbon than nitrogen to thrive, although both elements must be available to sustain life. Other conditions being favorable, the digestion will proceed at an optimal rate with a carbon to nitrogen ratio in the raw material of thirty to one. (Ref. 100, 118).

The best pH range for fastest anaerobic digestion is from near neutral to slightly basic: pH 6.8 to pH 8. A higher pH will be lowered after passage of sufficient (lost production) time by the generation of acidic carbon dioxide. A lower pH will cause cessation of digestion as the bacteria prove unable to absorb the acidity rapidly enough.

The best solids concentration for digestion in the biogas units is in the range of seven to nine percent by weight, the remaining raw material component being water. As most organic materials which have been used for anaerobic fermentation are greater than eighteen percent solids by weight, they are usually diluted with water. (Ref. 118). This concentration is controlled at the comminuters in the TERSA biogas subsystem.

5.4 EQUIPMENT DESIGN

The key element in the biogas process is the enclosed biomass digester tank. This tank is sealed off from the atmosphere (particularly oxygen) and has provisions for raw material inflow, gas outflow, and organic residue outflow. (See Figure 5-2).

Material may be fed to the digester in either batches or in a continuous manner. The Total Energy Recovery System for Agribusiness utilizes the continuous feeding method as it not only affords a more definite and regular output of biogas, but is also well suited to the types of organic waste utilized.

Hyacinths, waste from the greenhouse and mushroom crops, spent mushroom media, and feces and entrails from the pond activities - in short, contributions from all TERSA subsystems - are mixed with water, chopped to two inches or less in length as controlled by the comminuters, and pumped as slurry to the first stage of the two stage biogas units illustrated typically in Figure 5-2. The density of the slurry decreases with digestion and old slurry is displaced by new slurry at a rate determined by the time required for fermentation. Although a given unit of incoming slurry does not produce gas at a uniform rate over its entire fermentation period, uniformity of gas output is guaranteed by feeding small amounts into the primary tank at a daily rate that allows slurry replacement every sixty to seventy days. (Ref. 100).

TERSA biomass inputs are of such a size that a relatively large volume tank is required. For such a case, the two-stage gas plant is used as it makes tank sizes more practical. Digestion is initiated in the first tank and, when eighty percent of the gas has been generated, the spent slurry is displaced into the secondary tank for completion of digestion. (Ref. 118).

Based on biomass digestion inputs enumerated in the next section, TERSA has six two-stage biogas units of 2,500 cubic feet capacity per day each.

Some form of slurry agitation in the digester is desirable and, by using pump motivated feeding, this agitation is attained in the TERSA biogas units without requirement for other, mechanical agitation.

The temperature of the digesters is controlled by the addition of heat to maintain the desired 85°-105°F temperature range. This heating is accomplished by circulating hot water from the TERSA clean water heating loop through coils built into the digesters. Insulation for the digesters is provided to minimize this heating requirement.

Figure 5-2. TERSA Biogas Unit

5.5 INPUTS AND OUTPUTS

Based on waste outputs from the other Total Energy Recovery System for Agribusiness subsystems, Table 5-1 summarizes the biomass inputs.

Table 5-1
Inputs for Biomass Digestion on
an Averaged Daily Basis

<u>Source</u>	<u>Amount in Pounds</u>
Tomatoes	22
Cucumbers	20
Mushroom Media Excluding Hyacinth	1220
Hyacinth	794
Pond Animal Waste	5

Each pound of vegetative biomass input yields seven cubic feet of biogas when fully digested; each animal or animal waste pound of biomass input yields one cubic foot of biogas. (Ref. 100, 118). Consequently, the biogas output of TERSA on an averaged daily basis is 14,400 cubic feet. Biogas is sixty percent methane, hence the methane equivalent of this biogas is 8640 cubic feet.

Eighteen cubic feet of methane will produce one horsepower for one hour when burned in an engine. (Ref. 100, 118). On this basis the TERSA biogas subsystem yields sufficient methane to run twenty horsepower continuously.

6. INTEGRATION METHODOLOGY

6.1 INTRODUCTION

Integration of subsystem activities of the Total Energy Recovery System for Agribusiness must take place over several different areas:

- thermal cascading
- nutrient cycling
- space requirements
- economics

These integrations are carried on simultaneously as each is a function of the others.

6.2 TEMPERATURE CASCADE CONSIDERATIONS

Within the temperature range below that suitable for electric power generation, a number of agribusiness and industrial applications of geothermal heat are possible. Figure 6-1 shows the approximate midrange temperatures for geothermal fluids for the TERSA subsystems. (Ref. 93).

In the Total Energy Recovery System for Agribusiness pumps circulate clean hot water from the heat exchangers through the subsystem activities and back to the heat exchanger for reheating by the hydrothermal fluid. These activities are arranged in a temperature cascade: the activity with the highest temperature requirement for function (in TERSA, the refrigeration unit for temporary product storage) uses the heated water first, followed by the activity with the next highest requirement, and continuing through the system to the last and coolest requirement (here, the biogas units) prior to returning to the heat exchanger. The hot water system uses a series piping arrangement to obtain the benefits of a temperature cascade and in addition utilizes a parallel flow system to permit shared use of heat with flow regulated by control valves as required for maintenance of the desired thermal environments.

Actual heating requirements for TERSA are discussed in the next chapters and may be previewed by referring to Figure 8-2.

6.3 NUTRIENT CYCLING

This aspect of TERSA has been discussed previously and the reader is referred to Section 5.2 and Figure 5-1 for details.

6.4 SPACE CONSIDERATIONS

Each of the TERSA subsystem activities has service, preparation, and handling space associated with its controlled environment area. Examples of such associated space requirements are:

- heat exchangers
- vehicle access for harvests
- mushroom media preparation area
- refrigerated produce storage
- equipment servicing
- office space.

The design of TERSA results in a compact arrangement combining associated space requirements common to subsystems with individually required access corridors. The system design also takes account of relative locations dictated by thermal cascade and nutrient cycling requirements.

6.5 ECONOMIC CONSIDERATIONS

Subsystem activity sizes were predicated upon commercially successful independent individual enterprises.

TERSA was designed as a module for a family style business involving four to six working members; this is the same labor basis as actual independent subsystem commercial units of approximate minimum successful size. As there are three major activities in TERSA that result in marketable commercial products - greenhousing, mushroom culture, and prawn rearing - it was necessary to combine less than independent sized subsystem units in order to keep the module within the family sized activity constraint with little or no consequent market disruption.

For a starting point, TERSA subsystems were sized at one-third independent size for each of the three major commercial activities. As other subsystem integrations progressed, these commercial sizes were adjusted to obtain a balance of thermal, energy, nutrient, and space considerations, which in turn modified the commercial subsystem sizes - in other words, there was utilization of feedback between the engineering and economic studies.

Figure 6-1. TERSA Heating Fluid Temperatures

7. HYDROTHERMAL FLUIDS AND HEAT EXCHANGER SELECTION

7.1 INTRODUCTION

TERSA focuses on the low temperature geothermal fluids or hydrothermal resources spectrum which, due to its low thermodynamic potential, has not been extensively reported upon. The majority of the existing literature covers those higher temperature geothermal fluids suitable for electric power generation and the technology which has been developed thus far has sought solutions to problems related to power production. The Total Energy Recovery System for Agribusiness incorporates the technology which can be transferred from the field of geothermal power generation. Technology associated with sea water heat transfer applications is also referred to for comparable problems and solutions.

7.2 HYDROTHERMAL FLUIDS

As the Total Energy Recovery System for Agribusiness is designed for an average or typical application rather than for any specific site, an effort was made at the outset of the study to establish generalized hydrothermal fluid quality criteria.

Sources of geothermal fluids in the temperature range of 200°F to 300°F (90°C to 150°C) are suited for TERSA applications. Figure 7-1 shows the location of these hydrothermal sources in the western United States. (Ref. 127). These sources, classified as hot water systems, have waters ranging from very low salinity to brines of extreme salinity. The most common range of dissolved solids is from 0.1 to 1 percent (1000 to 10,000 ppm), but a few wells contain as high as 2 to 3 percent. (Ref 127).

Certain chemicals dominate these hot water systems. These chemicals are (Ref. 23, 95, 96, 97).

- hydrogen sulfide
- carbon dioxide
- ammonia
- silica
- sulfates, bicarbonates and chlorides as associated potentially with iron, magnesium, and calcium.

Each hydrothermal well has unique and individual properties with regard to solids content, chemical composition, gas content, water temperature and pressure.

Figure 7-1. Location of Hydrothermal Convection Systems in the Conterminous United States with Indicated Subsurface Temperatures between 90 and 150 degrees C. (Source: Ref. 127).

Typical water qualities from various hydrothermal sources were used in discussions with heat exchange equipment manufacturers to determine materials suitably resistant to scaling and corrosion, the major problems in heat transfer from geothermal fluids. These water qualities are displayed in the Appendix.

7.3 SCALING

Heat transfer surfaces, usually metal, are contained within a pressure vessel for isolation of a hot (geothermal) fluid from the secondary or cooler fluid; this comprises a heat exchanger. When scale deposits build up on the heat transfer surfaces, they act as insulation and retard the heat in being transferred. Consequently, a heat exchanger with scale on its heat transfer surface becomes less effective. In extreme cases scale deposits can actually block the flow of the scale carrying fluids through the heat exchanger.

A. Sulfate Scales

Sulfate scales can be formed in brines as large, relatively nonadherent crystals of gypsum, their stable low temperature phase. These crystals can be washed from heat transfer surfaces with high pressure water jets, a common heat exchanger cleaning method. The stable high temperature phase of sulfate scale, anhydrite, crystallizes slowly and supersaturates easily. (Ref. 98). Anhydrite forms a dense, adherent scale in concentrated brines and is difficult to remove by chemical or physical means.

For operation at the maximum system temperature (250°F), anhydrite scale formation can be avoided for anhydrite concentrations of less than 2,000 parts per million. Sulfate scaling is, in fact, generally minimized by not operating a heat exchange system in potentially troublesome regions of the temperature-solubility relationship. Brines have, however, been pretreated to extend the safe operating range. (Ref. 98).

B. Alkaline Scales

Alkaline scales are precipitated when carbon dioxide evolves from a liquid solution to the gaseous phase. Calcium carbonate deposits form at temperatures up to 180°F; magnesium hydroxide becomes the alkaline scale problem at higher temperatures. Alkaline scale formation, in general, increases with increasing dissolved solids, calcium content, pH, and temperature. (Ref. 33, 98).

Under TERSA's thermal operating conditions, magnesium hydroxide scaling would be expected. Should mechanical descaling not suffice, alkaline scales are acid soluble

and can be removed by treatment with inhibited acids. (Ref. 98). Alkaline scale deposits have been minimized by operating the system under pressure suitable for stabilization of the carbon dioxide constituent. (Ref. 23).

C. Silica Scales

Silica scales are less common than sulfate or alkaline scales in low temperature geothermal waters. (Ref. 96, 98, 103). Experience in Iceland (Ref. 64) has shown that scaling from siliceous materials is uncommon when reservoir temperatures are below 212°F (100°C), but may present a major problem when water is from high temperature reservoirs.

In general, the rates of silica scale deposition are complicated functions of temperature, temperature gradients, flow rate, turbulence, silica concentration, surface roughness, and concentration of suspended solids and other solutes. Equilibrium relations show that the initial solubility of silica can be repressed by high concentrations of solutes such as sodium chloride or carbon dioxide, present either naturally or by addition. Silica can form particularly hard to remove scales if permitted to concentrate sufficiently. (Ref. 4, 53). However, troublesome silica deposits within the Matsukawa (Japan) geothermal steam turbine were removed by washing them out with pure water. (Ref. 102).

7.4 CORROSION

Heat transfer surfaces are eaten away by corrosion. Corrosion is essentially an electrochemical process which takes place in the hydrothermal fluid situation when materials of different electrical potential are connected by the electrically conductive brine. Dissolved solids, particularly chlorides and sulphates, intensify the corrosive effect of dissolved gases like oxygen and carbon dioxide. The higher solids content increases the electrical conductivity of water, facilitating the flow of corrosion current which accelerates corrosion. (Ref. 33, 95).

Unfortunately, the hot water dominated geothermal systems are characterized by high specific conductances, high contents of chlorides and sulphates, and high cation concentrations of silica, sodium and potassium. (Ref. 95, 96, 103).

Various materials have shown corrosion resistance in some geothermal situations, although there are tradeoffs mitigating the selection of a "best" material. Lund (Ref. 95) recommends stainless steel for conditions where stray electrical currents causing electrolytic corrosion are significant. Hermannsson (Ref. 64) reports sodium silicate protects zinc coated iron and cast iron. Surface corrosion

rate studies for different materials with geothermal waters at 257°F (125°C) indicated austenitic stainless steels and titanium as attractive for heat exchanger use (Ref. 97). Copper Alloy No. 706 (10% nickel) tubes have shown excellent resistance to sea water, although this alloy has only fair resistance to corrosion by hydrogen sulfide and similar sulfur compounds. (Ref. 36, 122, 131). Titanium tubes have successfully replaced AISI type 304 stainless steel in a heat exchanger in the Cerro Prieto geothermal powerplant in Mexico. (Ref. 53).

7.5 HEAT REQUIREMENTS

The heat requirements for TERSA subsystems sized as discussed previously and based on an ambient temperature of 25°F are given in Table 7-1 in British thermal units per hour (Btuh):

Table 7-1

TERSA Heat Requirements

<u>Subsystem</u>	<u>Btuh</u>
Greenhouses	1,350,000
Ponds	7,800,000
Mushroom Houses	180,000
Refrigeration	1,000,000
Others	<u>100,000</u>
Subtotal	10,430,000
+15% losses	<u>1,564,500</u>
TOTAL, say	12,000,000 =====

7.6 CRITERIA FOR HEAT EXCHANGER SELECTION

On the basis of the preceding discussion and good engineering practice the following criteria were used for the heat exchanger selection for the Total Energy Recovery System for Agribusiness:

- Provision to be made for self-descaling or manual in-service descaling of scale deposits in addition to periodic tear down for cleaning.

- Material selected to be capable of sufficiently withstanding corrosion from geothermal fluids of up to 302°F (150°C) and 12,000 ppm total dissolved solids.
- A design temperature for the secondary fluid consistent with operation of TERSA's highest temperature requirement, the absorption cooling unit.
- Performance based on minimum flow on the clean water side to minimize system piping costs.
- Two heat exchanger units to carry the maximum winter heating load. Either unit may be isolated for service or repair during mild temperatures without requiring a system shutdown.
- Proven under as similar conditions as possible.
- Lowest cost consistent with engineering practice.

7.7 HEAT EXCHANGER SELECTION

The key factor in commercial heat exchanger selection for the hydrothermal fluid became the self-descaling or in-service descaling requirement. Recent experimental developments not yet available commercially that appear to offer some promise toward fulfilling this requirement include: improvements in Teflon processing and coating for heat exchanger tubes; fluidized bed heat exchangers; recirculating bed heat exchangers; and open channel heat exchangers. Three different methods that have been in use in industry for at least ten years were considered in the final selection:

- Modified Aerco Helitherm Heat Exchanger
- M.A.N. On-Load Cleaning System
- Amertap Tube Cleaning System

A. Modified Aerco Helitherm Heat Exchanger

The standard Helitherm Heat Exchanger is a vertical-cross flow unit, with modular helical coils mounted between vertical inlet and outlet risers. The primary fluid, generally steam, enters the coils from the inlet riser, flows through the coils in parallel, and discharges from the outlet riser. The secondary fluid flows through the shell from bottom to top, passing over the coils in series. The constant flexure of the helical coils under varying load conditions provides automatic self-descaling of brittle scale deposits on the coil exterior surfaces. Under extreme conditions, thermal shocking (consisting of rapid temperature change of the fluid in the shell) may be used for descaling. (Ref. 1).

For TERSA application it was intended to replace the primary fluid with cold water and use the geothermal fluid in place of the secondary fluid. This arrangement, if workable and economically feasible, would provide automatic descaling on the geothermal fluid side of the heat exchanger.

Aerco International, Inc., manufacturers of Helitherm Heat Exchangers, were contacted regarding viability of these units for TERSA. The proposed use of the heating fluid on the shell side of the heat exchanger raised two problems:

1. The manufacturer had never used this arrangement before and felt that expected high temperature swings on the tube side would result in unsatisfactory heat transfer operation.
2. The heat transfer rate is effectively reduced with consequent large heat transfer area requirements resulting in the need for an estimated nine units in series at a budget price on the order of \$120,000. (Ref. 1).

B. M.A.N. On-Load Cleaning System

This system is designed for tube and shell type heat exchangers and uses titanium wire brushes to serve each tube individually. The brush is stored in a cage at the end of the tube and passes through the tube to a cage at the opposite end by reversal of the brine flow direction through the tubes. Each brush effectively cleans the tube during its travel, with resulting loose scale flushed out by the flowing fluid. The entire cleaning cycle takes about eighty seconds and is automatically controlled to eliminate the possibility of dangerous waterhammer during flow reversal. The frequency of cleaning cycles can be controlled to match the scaling tendencies of the hydrothermal fluid.

The On-Load system has been reported quite effective in improving the performance of heat exchangers by removing scale and eliminating the galvanic cells causing corrosion associated with that scale. (Ref. 17, 92, 98). The budget cost estimate for incorporating this system in a TERSA heat exchanger is \$2,600. (Ref. 2).

C. Amertap Tube Cleaning System

The Amertap System has been used to provide continuous mechanical tube cleaning of tube and shell condensers for steam in powerplants. This system consists of specially engineered abrasive rubber balls of slightly larger diameter than the tubes that continuously circulate through the heat exchanger. The constant rubbing action helps keep the tube walls clean.

The number of balls used is such that each tube receives a ball on the average of one every five minutes. The closed loop circuit for the balls has an in-line screening device at the discharge end of the heat exchanger which captures the balls and reroutes them through a collector unit which returns them to the heat exchanger. At this collector unit, the ball cycle can be interrupted at any time to count the balls, check sizes or take them temporarily out of service without interrupting the heat exchanger.

No data on successful application of the Amertap cleaning system for heat exchangers using water at 250°F presently exists, but, with the use of high temperature balls, this system may provide an alternate method of descaling the heat exchanger. The budget cost estimate for incorporating the Amertap Cleaning System in a TERSA heat exchanger is \$18,000. (Ref. 5).

D. Material Selection

From previous discussion and manufacturer's suggestions, copper-nickel, stainless steel, and titanium were considered for tube materials. Titanium tubing has its largest single use in the handling of sea water and brackish waters where chloride levels above 200 ppm cause most other metals to fail (Ref. 110) and has in fact been successfully employed in such environments where stainless steels and copper-nickels had already failed. In addition to titanium's corrosion resistance, it has excellent resistance to erosion from fluids with suspended solids flowing at very high velocities. Titanium exchangers do not foul as rapidly or to the same degree as other metallic exchangers because the titanium oxide film which protects the titanium from corrosion and erosion is also non-wetting and retards scale build-up. (Ref. 110).

There are an estimated seven million linear feet of titanium tubing in use in the United States for heat transfer service involving salt or brackish water including use by utilities, seawater distillation plants, and refineries. The resistance of titanium to salt water has been substantiated by this actual service. Titanium is considered practically immune to corrosion in brines at temperatures up to 250°F (120°C); this resistance is little modified by the presence of hydrogen sulfide and natural pollutants of seawater. At TERSA temperatures, corrosion taking place under scale and hydrogen embrittlement are also unlikely. (Ref. 69).

For purposes of comparison, budget estimates were obtained for copper-nickel and titanium tube heat exchangers for two six million Btuh TERSA configurations under study. In the first case, 250 gallons per minute

(gpm) of hot fluid entered each heat exchanger at 250°F and exited at 200°F to heat 120 gpm of clean fluid from 100°F to 200°F; the estimated cost for titanium was \$17,300 and for copper-nickel was \$13,600. In the second case, 180 gpm of hot fluid went from 250°F to 180°F in heating 120 gpm from 100°F to 200°F; the titanium estimate was \$21,000 compared to \$14,500 for copper-nickel. (Ref. 105).

Based upon the more likely success of titanium in the nonspecific hydrothermal fluid and a conservative economic approach, titanium tube heat exchangers per the first case above were selected. Figure 7-2 illustrates the heat exchanger selection. For two such heat exchangers with M.A.N. On-Load Cleaning, the budget estimate is \$39,800.

Figure 7-2. TERSA Heat Exchanger

8. THE SYSTEM

8.1 INTRODUCTION

The design of the Total Energy Recovery System for Agribusiness passed through stages of iteration based upon previously discussed requirements and is presented in schematic diagram as finally evolved in Figure 8-1.

8.2 SYSTEM DESCRIPTION

As depicted in Figure 8-1, the hydrothermal fluid passes through the heat exchangers under pressure and is reinjected with most of its original chemical content intact. A pumped hot water heating system of the type commonly utilized in institutional applications is piped to the clean water side of TERSA's heat exchanger loop.

The highest temperature clean water (200°F) is used in the absorption refrigeration system used for product storage. Higher temperature hot water is also used for space heating of the greenhouses, mushroom houses, and the laboratory/office. Following these applications, the water is used for prawn pond heating, followed by biomass digester heating and, finally, the water is recirculated through the heat exchanger.

Figure 8-1 also indicates the flow of biogas and the accompanying production of fertilizer and compost.

The uniqueness of the Total Energy Recovery System for Agribusiness lies in its combination of cycles such that they use their waste products and geothermal energy to serve each other's needs. Furthermore, the accelerated growing rates of each cycle would promote accelerated cycling of energy so that all cycles tend towards very intensive production, both per acre and per energy unit input, although conservative production and energy requirement figures have been used to reflect minimum expectations.

8.3 SYSTEM SITE PLAN

A TERSA family sized module occupies a little over six acres in the manner shown in Figure 8-2 and as sized for average conditions. Features are:

- a hydrothermal source providing 500 gpm at 250°F
- three greenhouses of 3000 square feet each
- three mushroom houses, each with 4000 square feet of bed space
- six prawn ponds of one-half acre each
- six biogas units, each of 2500 cubic feet daily biogas production capacity

Figure 8-1. TERSA Schematic Diagram

- two heat exchangers of six million British thermal units per hour (Btuh) capacity each
- two ten horsepower engine-generator sets to be powered by biogas
- refrigerated temporary storage area capable of holding 1000 pounds of prawns at 40°F, 2500 pounds of tomatoes or cucumbers at 50-55°F, and 3000 pounds of mushrooms at 40°F
- a combination laboratory and office occupying 900 square feet
- circulating pumps and various appurtenant facilities.

Figure 8-2 also shows the major site piping arrangements and indicates pipe sizes and subsystem heat requirements.

8.4 OPERATION AND MAINTENANCE

Subsystem operational requirements have largely been discussed in their respective chapters and are summarized following.

Tomato crop labor consists of: growth media preparation; planting; stringing; pruning and training; pollination; fertilization and irrigation; pest control; harvesting; packing and storage; and postharvest plant removal. Labor is conservatively estimated to require 2100 hours for the single annual TERSA tomato crop. (Ref. 74, 77).

Cucumber crop labor involves the same activities as for the tomatoes except for pollination and is conservatively estimated to require 1700 hours for the single annual TERSA cucumber crop. (Ref. 73, 77).

Labor for mushroom culture includes: compost preparation; bed filling; casing soil preparation; spawn planting; casing; irrigation; pest control; harvesting; packing and storage; and house cleaning. These activities are conservatively estimated to require 6000 hours for the two and one-half annual crops from this component of the Total Energy Recovery System for Agribusiness. (Ref. 16, 80, 87).

Prawn pond labor requirements are conservatively estimated to be 2500 hours per year for TERSA's three acres of ponds and consist of: pond preparation; introduction of juveniles; feeding; weeding; silt and pest control; harvesting; packing and storage; and postharvest pond treatment. (Ref. 48, 115).

Other required labor includes: hyacinth harvesting; biomass preparation for digestion; distribution of digested biomass; heat exchanger maintenance; material handling equipment maintenance; general office work; and miscellaneous other

Figure 8-2. TERSA Site Plan

activities. This labor requirement is estimated to consume 1100 hours per year for biomass handling and 800 hours for other activities.

Table 8-1 summarizes annual labor requirements for TERSA.

Table 8-1
Annual TERSA Labor Requirements

<u>Subsystem</u>	<u>Labor Hours</u>
Greenhouse Tomatoes	2,100
Greenhouse Cucumbers	1,700
Mushroom Culture	6,000
Prawn Ponds	2,500
Biomass Handling	1,100
Other Activities	<u>800</u>
Subtotal	14,200
+20% contingency	<u>2,840</u>
TOTAL, say	17,000 =====

Costs for supplies used in the agribusiness subsystems include: growing media; chemicals; plants, spawn, and juvenile prawns; support strings and clips for the greenhouse operations; water; electricity; and packing. Table 8-2 summarizes lumped operation and maintenance costs for TERSA based on published data updated to 1977. (Ref. 16, 73, 74, 77, 80, 87, 115).

Table 8-2
Annual TERSA Operation and Maintenance Requirements

<u>Subsystem</u>	<u>Cost</u>
Greenhouse Tomatoes	\$ 1,100
Greenhouse Cucumbers	\$ 1,300
Mushroom Culture	\$ 5,000
Prawn Ponds	<u>\$11,000</u>
Subtotal	\$18,400
+20% contingency	<u>\$ 3,680</u>
say	\$22,100
Less: replacement value of electricity produced by biogas at \$0.04/kWhr	<u>\$ 5,200</u>
TOTAL, say	<u>\$16,900</u> =====

8.5 SYSTEM ECONOMICS

Capital costs for the Total Energy Recovery System for Agribusiness are based on most recent published data updated to 1977 and on 1977 budget quotations from suppliers. Table 8-3 summarizes estimated TERSA installed capital costs and their bases.

Table 8-3
TERSA Capital Cost Summary

<u>Item</u>	<u>Basis</u>	<u>Total Cost</u>
Greenhouses and Equipment	\$4.80/sq. ft.	\$43,200
Greenhouse Site Preparation	\$2.00/sq. ft.	\$18,000
Mushroom Houses and Site	\$7.50/sq. ft. of floor	\$30,000
Ponds	\$4,200/acre	\$12,600
Biogas Units	\$6,400/unit	\$38,400
Heat Exchangers	\$20,000/unit	\$40,000
Refrigeration	\$24,000/unit	\$24,000
Piping	\$92,500 lump sum	\$92,500
Lab/Office	\$20.00/sq. ft.	\$18,000
Pumps and Motors	\$2,000/unit	\$ 4,000
Engine-Generator Sets	\$2,000/unit	\$ 4,000
Material Handling Equipment	\$23,500 lump sum	\$23,500
Miscellaneous Capital Costs	\$10,000 lump sum	<u>\$10,000</u>
	Subtotal	\$358,200
	+20% contingency	<u>\$71,600</u>
	TOTAL	<u>\$429,800</u> =====

The figures in Tables 8-1 through 8-3 and sales figures discussed separately in previous chapters provide the basis for summary of system economics for the Total Energy Recovery System for Agribusiness as expressed in Table 8-4 following. TERSA economics based on other yields and pricing are discussed in the Appendix.

Table 8-4
TERSA Economic Summary

Total Product Gross Sales	\$151,200
Less: Labor at \$3.00/hour	\$ 51,000
Less: Operation and Maintenance Costs	<u>\$ 16,900</u>
YIELDS: Net Operating Profit	\$ 83,300 =====
Discounted Cash Flow Present Value of \$83,300 Flow Annually for 17 years at 7 percent	\$813,200
Less: Capital Costs	<u>\$429,800</u>
YIELDS: Capital available for site, well, and return on investment	\$383,400 =====

Due to the generalized nature of this non-site specific study, it is impractical to reasonably estimate land acquisition and well costs and, consequently, the rate of return on investment is calculated without these costs. Assuming that the yearly net operating profit remains constant as annual cash flow, the rate of return on the non-site capital investment for seventeen years amounts to slightly over eighteen percent. (Ref. 56, 61). This presumed seventeen year useful life for a typical TERSA module is based on average estimates for minimum depreciation periods for pumps, piping systems, engines, and similar equipment as recommended by the American Society of Heating, Refrigerating, and Air Conditioning Engineers. (Ref. 3). It remains for a site specific TERSA design for determination of the expected rate of return for the total investment.

Based on an average TERSA demand of six million Btuh and seventeen year system life, TERSA can afford to pay \$383,400 total or an average of \$0.43 per million Btu for well and land and still break even on capital investment. This energy cost is within a published nonelectric application range (Ref. 64) of \$0.37 to \$5.22 per million Btu, with values around \$1.00 per million Btu being most common. Finally, for purposes of energy comparison, the reader should note that the use of geothermal heat in the Total Energy Recovery System for Agribusiness replaces over

480,000 gallons of oil that would be required for the same amount of heating.

9. CONCLUSIONS AND RECOMMENDATIONS

An ERDA funded engineering and economic study has been made to determine a practical balance of selected agribusiness subsystems resulting in realistic estimated produce yields for a geothermally heated system known as the Total Energy Recovery System for Agribusiness. The subsystem cycles for an average application at an unspecified hydrothermal resources site in the western United States utilize waste and by-products from their companion cycles insofar as practicable.

Based on conservative estimates of current controlled environment yields, produce wholesale market prices, production costs, and capital investment required, it appears that the family operation sized TERSA module presents the potential for marginal recovery of all capital investment costs. Actual determination of margin of investment recovery can accurately be made upon establishment of a specific project site with its affiliated land, well system, market and production costs.

In addition to family or small cooperative farming groups TERSA has potential users in food oriented corporations and large cooperative agribusiness operations. For all practical purposes, the Total Energy Recovery System for Agribusiness family sized module may be scaled up linearly in size, production, and investment within a maximum scale up multiplier of around ten, as limited primarily by the size of the geothermal resource.

TERSA is flexible in its adaptability to local conditions as its subsystem agribusiness cycles can be modified in size and type of crops produced. The system size can be increased modularly or designed for less quantified additions. Finally, control system modifications can accomodate labor intensive or automated objectives as well as further protecting the environment and conserving water.

TERSA's economic viability in this generalized study indicates that there should be a study leading to selection of a specific site/area operation. Such a study will determine: local markets and requirements; heat exchanger construction; climate; land costs and soil qualities; labor supply and costs; quality and cost of water; availability of beneficial local resources; and degree of prospective local participatory interest and capability.

Educational, research and development interests can best be served by construction of a demonstration plant for a TERSA module to evaluate the following subsystem functions:

- year round heated giant prawn farming
- interchange of nutrients between the agribusiness subsystems

- hydrothermal descaling heat exchanger design
- containment of water hyacinth in conjunction with a module designed for water conservation.

REFERENCES

1. Aerco International; Quotation; 1977.
2. American M.A.N. Corp.; Quotation; New York; 1977.
3. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.; ASHRAE Handbook and Product Directory: 1973 System; ASHRAE; New York; 1973.
4. American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.; ASHRAE Handbook of Fundamentals; ASHRAE; New York; 1972.
5. Amertap Corp.; Quotation; Mineola, New York; 1977.
6. Ampco Metal; Ampco Application Data; Milwaukee; 1976.
7. Anonymous; "Building the Fact Bases and Methods for Sound Energy Decisions"; EPRI Journal; Vol. 2; No. 1; January/February 1977; pp. 44-45.
8. Anonymous; "Cattle Dung Offers Energy Relief for Rural India"; Energy International; April 1975; pp. 25-6.
9. Anonymous, "Coal: The R&D Pivot for New Energy Fuels, Cycles, and Storage"; EPRI Journal; Vol. 2; No. 1; January/February 1977; pp. 8-21.
10. Anonymous; "Greenhouse and Bedding Plant Issue"; American Vegetable Grower, Western Edition; Vol. 24, No. 11; November 1976.
11. Anonymous; Report to the Mushroom Industry Concerning Costs of Growing Mushrooms; The Department of Agricultural Economics and Rural Sociology of the Pennsylvania State University; 1974.
12. Anonymous; "Shellfish Research"; The Commercial Fish Farmer; July/August 1975; p. 25.
13. Anonymous; Vegetative Water Use in California, 1974; Bulletin No. 113-3; State of California, The Resources Agency, Department of Water Resources; April 1975.
14. Armstead, Christopher H., Editor; Geothermal Energy; UNESCO; Paris; 1973.
15. Atkins, Fred C.; Mushroom Growing To-Day; The MacMillan Company; New York; 1966.
16. Atlee, Charles B; 1959 Sample Inputs and Costs for Mushrooms, Santa Cruz County; University of California Extension; Santa Cruz; 1959.

17. Banta, Vern E.; "Continuous Cleaning Ups Chiller Performance"; Power; June 1974.
18. Bardack, John E., Ryther, John H., and McLarney, William O.; Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms; Wiley Interscience; New York; 1972.
19. Barmettler, Edmund R.; Geothermal Energy Utilization; University of Nevada; Reno.
20. Barnea, Joseph; "Economics of Multi-Purpose Use of Geothermal Resources"; Geothermal Energy Magazine; November 1974; pp. 29-34.
21. Baumeister, Theodore, Editor; Mark's Standard Handbook for Mechanical Engineers; Seventh Edition; McGraw-Hill Book Company; New York; 1967.
22. Beall, Sam E.; "Agro-Geothermal Production Facilities"; Geothermal Energy Magazine; October 1973; pp. 23-4.
23. Belteky, L.; "Problems Related to Operating Thermal Wells Subject to Scaling in Hungary"; Geothermics; Vol. 4; No. 1-4; 1975; pp. 57-65.
24. Berry, James W., and Miller, Herman, Jr.; A Demonstration of Thermal Water Utilization in Agriculture; EPA-660/2-70-01; Office of Research and Development, U.S. Environmental Protection Agency; Washington, D.C.; April 1974.
25. Besemer, Seward T.; Carnation Culture in San Diego County; University of California, Agricultural Extension Service; San Diego County; 1975.
26. Besemer, Seward T.; Economics of U.S. Carnation Industry; University of California, Agricultural Extension Service; San Diego County; 1967.
27. Besemer, Seward T., and Close, D.H.; Summary of Carnation Flower Production Study, San Diego County; University of California, Agricultural Extension Service; San Diego County; 1963.
28. Besemer, Seward T. and Phelps, Fisk H.; Growing Carnations in San Diego County; University of California, Agricultural Extension Service; San Diego County; 1958.
29. Bird, Kermit; "Some Economic Projections of the U.S. Mushroom Industry"; speech given to American Mushroom Institute Conference; Wilmington, Delaware; September 6, 1969.
30. Boldizar, T.; "Geothermal Energy Use in Hungary"; Geothermal Energy Magazine; April 1975; pp. 5-13.

31. Bowen, R.G., and Peterson, N.V.; Thermal Springs and Wells in Oregon; State of Oregon; Portland; 1970.
32. Campbell, Glen; "Geothermal Hydroponics"; Geothermal Energy Magazine; August 1973; pp. 14-16.
33. Carrier Air Conditioning Company; Carrier System Design Manual - Water Conditioning; Syracuse, New York; 1963.
34. Carrier Air Conditioning Company; Quotation; San Francisco; 1977.
35. Chapman, Alan J.; Heat Transfer; The MacMillan Company; New York; 1960.
36. Copper Development Association, Inc.; Technical Report; New York; August 1973.
37. Corbin, John S.; Aquaculture in Hawaii, 1976; State of Hawaii, Department of Planning and Economic Development; January 1976.
38. Crane Company; Flow of Fluids; Technical Paper No. 410; New York; 1974.
39. Davidson, Jackson; A Greenhouse Grower's Checklist; 75-SP/3006; University of California; 1974.
40. Doucet, Lawrence G.; "Energy from Solid Waste: The Promise, The Potential"; Specifying Engineer; December 1976; pp. 110-11.
41. Eagleson, Peter S.; Dynamic Hydrology; McGraw-Hill Book Company; New York; 1970.
42. EG&G Idaho, Inc. and Idaho National Engineering Laboratory; Geothermal R&D Project Report for Period July 1, 1976 to September 30, 1976; TREE 1030; National Technical Information Service; Springfield, Virginia; 1976.
43. Engineers and Fabricators Company; Quotation; Houston, Texas; 1977.
44. Energy Research and Development Administration; Fuels from Biomass Program: Program and Project Status; Division of Solar Energy; Washington, D.C.; November 1976.
45. Energy Research and Development Administration; Geothermal Resources (A Bibliography); United States ERDA Technical Information Center; Oak Ridge, Tennessee; 1975.
46. Eriksen, L.F., and Fogleman, S.F.; Geothermal Plant Design Considerations; ASCE National Structural Engineering Meeting; San Francisco; April 9-13, 1973.

47. Farnham, Delbert S., and Parsons, Philip S.; Typical Costs of Developing Greenhouse Carnations, Monterey and Santa Cruz Counties; Agricultural Extension, University of California; Santa Cruz; 1972.
48. Fujimura, T.; Development of a Prawn Culture Industry in Hawaii, Job Completion Report; National Marine Fisheries Service; 1974.
49. Fujimura, T.; Notes on the Development of a Practical Mass Culturing Technique of the Giant Prawn Macrobrachium Rosenbergii; UNFAO; Indo-Pacific Fisheries Council; 1966.
50. Fujimura, T. and Okamoto, H; Notes on Progress Made in Developing a Mass Culturing Technique for Macrobrachium Rosenbergii in Hawaii; UNFAO; Indo-Pacific Fisheries Council; 1970.
51. Furuta, Tokuji; The Environment and Nursery Production, Nursery Management Handbook - Section IX; AXT-320; University of California, Agricultural Extension Service; Davis; 1970.
52. Genders, Roy; Mushroom Growing for Everyone; Faber and Faber; London; 1969.
53. Geothermal Resources Council; Proceedings of Second Workshop on Materials Problems Associated with the Development of Geothermal Energy Systems; Geothermal Resources Council; Davis, California; 1975.
54. Godfrey, Robert Sturgis, Editor-in-Chief; Means Building Construction Cost Data 1977; Robert S. Means Co., Inc.; Duxbury, Massachusetts; 1977.
55. Goodland, R. and Tillman, G; Guatemala National Energy Master Plan: Environmental Assessment; The Cary Arboretum; Millbrook, NY; December 1975.
56. Grant, Eugene L., and Ireson, W. Grant; Principles of Engineering Economy; Fifth Edition; The Ronald Press Company; New York; 1970.
57. Grist, D.H.; Rice; Tropical Agricultural Series; London; 1969.
58. Hall, Beverly A.; Materials Problems Associated with the Development of Geothermal Resources; Geothermal Resources Council; Davis, California; 1975.
59. Hannah, Judith L.; The Potential of Low Temperature Geothermal Resources in Northern California; 1975 Edition; Report TR13; Division of Oil and Gas, State of California; Sacramento; 1975.

60. Hasek, Raymond F; "Sources of Horticultural Information"; reprinted from The Florida Foliage Grower; Vol. 10; No. 3 and 4; 1973.
61. Hewlett-Packard Company; HP-25 Applications Programs; 1975.
62. Hickling, C.F.; Fish Culture; Faber and Faber; London; 1962.
63. Hickling, C.F.; The Farming of Fish; Pergamon; New York; 1968.
64. Howard, J.H., Editor; Present Status and Future Prospects for Nonelectrical Uses of Geothermal Resources; Lawrence Livermore Laboratory, University of California, UCRL-51926; October 15, 1975.
65. Howard, J.H.; Principal Conclusions of the Committee on the Challenges of Modern Society Non-Electrical Applications Project; reprinted by Lawrence Livermore Laboratory; University of California; Livermore, California; 1975.
66. Huguenin, John E.; Heat Exchangers for Use in the Culturing of Marine Organisms; Contribution No. 3382 from the Woods Hole Oceanographic Institute; 1976.
67. Huguenin, John E. and Ryther, John H.; "The Use of Power Plant Waste Heat in Marine Aquaculture"; Marine Technology Society Tenth Annual Conference Proceedings; 1974.
68. International Engineering Co., Inc.; Proposal For Engineering and Economic Study: Non-Electric Applications of Geothermal Heat; made to the U.S. Energy Research and Development Administration, Division of Geothermal Energy; April 1976.
69. Jacobs, R.L. and McMaster, J.A.; "Economical Solution to Heat Exchanger Corrosion"; Materials Protection and Performance; July 1972; p. 33.
70. Jesse, E.V. and Machado, M.J.; Trends in Production and Marketing of California Fresh Market Tomatoes; 75-BL/1871; University of California; Davis; 1974.
71. Johnson, Bill; "Aquaculture at Oregon Institute of Technology"; Geo-Heat Utilization Center Quarterly Bulletin; Oregon Institute of Technology; Klamath Falls, Oregon; July 1976.
72. Johnson, Hunter, Jr.; Greenhouse Crop Wholesale Prices; unpublished; 1977.
73. Johnson, Hunter, Jr.; Greenhouse Cucumber Production; Leaflet 2775; University of California; Riverside; 1975.
74. Johnson, Hunter, Jr.; Greenhouse Tomato Production; Leaflet 2806; University of California; Riverside; 1975.

75. Johnson, Hunter Jr.; Greenhouse Vegetable Production; OSA #249; University of California; Riverside; 1974.
76. Johnson, Hunter, Jr.; Some References for Greenhouse Vegetable Production and Hydroponics; University of California; Riverside; 1975.
77. Johnson, Hunter, Jr. and Rock, Robert C.; Sample Costs for Producing Greenhouse Tomatoes and Cucumbers in California; University of California; Riverside; 1975.
78. Karmeli, David and Keller, Jack; Trickle Irrigation Design; Rain Bird Sprinkler Manufacturing Corp.; Glendora, California; 1975.
79. Keifer, Elizabeth; "The Pitfalls and Promise of Fish Farming"; San Francisco Sunday Examiner and Chronicle; October 10, 1976.
80. Kinrus, Aron; Information on Mushroom Growing and the Mushroom Industry; American Mushroom Institute; Kennett Square, Pennsylvania; February 1977.
81. Kneebone, Leon R.; "Composts for Mushroom Culture"; Market Growers Journal; June 1955; pp. 16-17.
82. Kneebone, Leon R.; Mushroom Research Theses at the Pennsylvania State University; Mushroom Research Center; Pennsylvania State University; November 1976.
83. Knight, Allen W.; Laboratory Studies on Selected Nutritional, Physical and Chemical Factors Affecting the Growth, Survival, Respiration, and Bioenergetics of the Giant Prawn, Macrobrachium Rosenberqii; Water Science and Engineering Paper No. 4501; University of California Hydrobiology Laboratory; Davis; March 1976.
84. Knott, James E.; Handbook for Vegetable Growers; John Wiley & Sons, Inc.; New York; 1957.
85. Kreith, Frank; Principles of Heat Transfer; Second Edition; International Textbook Company; Scranton, Pennsylvania; 1966.
86. Kruger, Paul, and Otte, Carel, Editors; Geothermal Energy; Stanford University Press; Stanford, California; 1973.
87. Lambert, Edmund B.; Mushroom Growing in the United States; USDA Farmers Bulletin No. 1875; 1963.
88. Lambert, Louis F.; Practical and Scientific Mushroom Culture; Louis F. Lambert, Inc.; Coatesville, Pennsylvania; 1965.

89. Lee, Charles H.; "Transpiration and Total Evaporation"; in Hydrology, edited by Oscar E. Meinzer; Dover Publications, Inc.; New York; 1942.
90. Lee, Jasper S.; Commercial Catfish Farming; The Interstate Printers and Publishers, Inc.; Danville, Illinois; 1973.
91. Leedahl, Alton O.; "The Closed-Loop Food Production System: A New Concept"; Agricultural Engineering; July 1976; pp. 33-35.
92. Leitner, G.F.; Energy Analysis for Water Chillers and Effect of "ON-LOAD" Cleaning of Condenser Tubes on Performance: Some Case Histories; Purdue Research Foundation; Purdue University; 1976.
93. Lindal, B.; "Industrial and Other Applications of Geothermal Energy"; in Geothermal Energy, edited by Christopher H. Armstead; UNESCO; Paris; 1973.
94. Linsley, Ray K., Jr., Kohler, Max A., and Paulhus, Joseph L.H.; Hydrology for Engineers; McGraw-Hill Book Company, Inc.; New York; 1958.
95. Lund, J.W., Silva, Jay F., Culver, Gene, Lienau, P.J., Svanevik, L.G., and Anderson, S.D.; Corrosion of Downhole Heat Exchangers; for ERDA/INEL Contract No. E(10-1)-1548; Geo-Heat Utilization Center; Klamath Falls, Oregon; October 1976.
96. Mariner, R.J., Rapp, J.B., Willey, L.M., and Presser, T.S.; The Chemical Composition and Estimated Minimum Thermal Reservoir Temperatures of Selected Hot Springs in Oregon; United States Geological Survey Open-File Report; Menlo Park, California; March 1974.
97. Marshall, T., and Braithwaite, W.R.; "Corrosion Control in Geothermal Systems"; in Geothermal Energy, edited by Christopher H. Armstead; UNESCO; Paris; 1973; pp. 151-160.
98. McIlhenny, W.F., and Zeitoun, M.A.; "A Chemical Engineer's Guide to Seawater"; Chemical Engineering; November 3 and November 17, 1969.
99. Milora, Stanley L., and Tester, Jefferson W.; Geothermal Energy as a Source of Electric Power; The MIT Press; Cambridge, Massachusetts; 1976.
100. Mother Earth News, Editor; Handbook of Homemade Power; Bantam Books, Inc.; New York; 1974.
101. Muhlfeld, Liz; "Fish, the Need to Know"; Rockerfeller Foundation Illustrated; December 1976.
102. Nakanishi, H., Iwai, N., and Miyazaki, M.; "Geothermal Power Plant"; Toshiba Review; November 1970; pp. 4-11.

103. Olmsted, F.H., Glancy, P.A., Harril, J.R., Rush, F.E., and VanDemburgh, A.S.; Preliminary Hydrogeological Appraisal of Selected Hydro-Thermal Systems in Northern and Central Nevada; United States Geological Survey Open-File Report 76-76; Menlo Park, California; 1975.
104. Onorato and Co.; Wholesale Quotations; San Francisco; 1977.
105. Patterson-Kelley Company; Quotation; San Francisco; 1977.
106. Peterson, Richard E., and El-Ramly, Nabil; "The Worldwide Electric and Nonelectric Geothermal Industry"; Geothermal Energy Magazine; November 1975; pp. 4-14.
107. Pflauder Company; Quotation; Rochester, New York; 1977.
108. Porter, Charles W.; "Mushroom Market Developments"; Mushroom Industry Short Course; Pennsylvania State University; June 1972.
109. Potter, Charles H.; Greenhouse, Place of Magic; A Sunrise Book; New York; 1976.
110. Pudlock, Jay R.; Comparative Costs of Metallic Corrosion Resistant Shell and Tube Heat Exchangers; ASTM B-10 Committee Symposium; New Orleans, Louisiana; November 19, 1975.
111. Reistad, Gordon M.; Analysis of Potential Non-Electric Applications of Geothermal Energy and their Place in the Economy; UCRL-51747; Lawrence Livermore Laboratory, University of California; February 14, 1975.
112. Rodale, J.I.; The Complete Book of Composting; Rodale Books, Inc.; Pennsylvania; 1975.
113. Roper IBG; Greenhouse Quotation; San Jose, California; 1977.
114. Rosenbruch, Jimmie C., and Bottge, Robert G.; "Geothermal Agricultural Applications - Hobo Wells Hydroponics"; Geothermal Energy Magazine; October 1976; pp. 36-38.
115. Shang, Yung C. and Fujimura, Takuji; The Production Economics of Fresh Water Prawn (Macrobrachium Rosenbergii) Farming in Hawaii; Draft; Hawaii Institute of Marine Biology and Anuenue Fisheries Research Center; 1977.
116. Short, Ted H., Badger, Philip C. and Roller, Warren L.; "OARDC's Solar-Heated Greenhouse"; Agricultural Engineering; July 1976; pp. 30-32.
117. Sims, William L.; Growing Mushrooms; Leaflet 2640, University of California; Cooperative Extension; 1976.
118. Singh, Ram Bux; Bio-Gas Plant; Mother's Print Shop; Hendersonville, N.C.; 1975.

119. Smil, Vaclav; "China Opts for Small Scale Energy Techniques"; Energy International; February 1976; pp. 17-18.
120. Sparrow, E.M., and Cess, R.D.; Radiation Heat Transfer; Brooks/Cole Publishing Company; Belmont, California; 1966.
121. Swink, D.G., Schultz, R.J. and Oswald, A.J.; "Geothermal Energy - An Integrated Use Plan"; Geothermal Energy Magazine; April 1976; pp. 21-23.
122. Thomasson, P.M.; Startup Considerations for a Once-Through Sea Water Cooling System; ASME Paper No. 73-IPWR-3; 1973.
123. Tongiorgi, E., Editor; "Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources"; Geothermics; Volume 2; Parts 1 and 2; 1970.
124. Trane Company; Quotation; San Francisco; 1977.
125. Wehlage, Edward F.; The Basics of Applied Geothermal Engineering; Geothermal Information Services; West Covina, California; 1976.
126. Weldon, L.W., Blackburn, R.D., and Harrison, D.S.; "Common Aquatic Weeds"; Agricultural Handbook No. 352; Agricultural Research Service, USDA; 1969; p. 2.
127. White, D.E., and Williams, D.L., Editors; Assessment of Geothermal Resources of the United States - 1975; Geological Survey Circular 726; United States Department of the Interior, Geological Survey; Washington, D.C.; 1975.
128. Williams, D.W., McCarty, T.R., Morris, G.R., Gunkel, W.W., and Price, D.R.; "Utilization of Biogas for Farm Production Energy"; Transactions of the ASAE - 1976; pp. 1034-1040, 1044.
129. Wolverton, B.C., Barlow, R.M., and McDonald, R.C.; "Application of Vascular Aquatic Plants for Pollution Removal, Energy, and Food Production in a Biological System"; NASA Technical Memorandum TM-X-72726; National Space Technology Laboratories; Bay St. Louis, Mississippi; May 1975.
130. Wolverton, B.C., McDonald, R.C., and Gordon, J.; "Bio-Conversion of Water Hyacinths into Methane Gas: Part 1"; NASA Technical Memorandum TM-X-72725; National Space Technology Laboratories; Bay St. Louis, Mississippi; July 1975.
131. Uhlig, Herbert H.; Corrosion and Corrosion Control; Second Edition; John Wiley and Sons, Inc.; New York; 1971.
132. USDA Crop Reporting Service; Wholesale Quotations; San Francisco; March 9, 1977.

133. Zumberge, James H., and Ayers, John C.; "Hydrology of Lakes and Swamps"; in Handbook of Applied Hydrology, edited by Ven Te Chow; McGraw-Hill Book Company; 1964; pp. 23-1 to 23-33.

APPENDIX

A. GEOTHERMAL WATER QUALITIES

Typical water qualities from various hydrothermal sources that were used in selection discussions with heat exchange equipment manufacturers are given in Tables A-1 through A-3 following.

Table A-1. Chemical Analyses of Water
from Selected Springs in Colorado
(Analytical results in parts per million.)

No.	Name	Discharge (gpm)	Temp. (°F)	Silica (Si)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)	Chloride (Cl)	Sulphate (SO ₄)	Bicarbonate (HCO ₃)
1	Routt	130	150	88	162	11	8	-	137	44	146
2	Steamboat Springs	2,000	150	85	2048	155	113	32	1346	486	3253
3	Eldorado	10	70	17	17	1	10	4	7	38	46
4	Glenwood Springs	400	150	37	6950	460	431	91	11025	1194	437
5	Buena Vista (Cottonwood)	150	144	61	81	34	5	3	28	108	87
6	Mount Princeton	300	150	60	38	32	11	7	12	62	86
7	Poncha Spgs	500	168	80	174	21	18	2	55	199	221
8	Waunita (Tomichi)	1,000	160	86	146	15	12	3	20	179	175
9	Powderhorn	100	114	80	267	75	133	49	120	132	1107
10	Ridgeway	300	132	58	374	102	274	21	103	1287	278
11	Wagon Wheel Gap	100	131	94	420	276	68	18	205	210	1048
12	Ouray	200	158	52	81	45	383	11	51	1016	37
13	Pagosa Spgs.	600	158	68	525	370	247	17	180	1054	636

Source: Geothermal Energy - Jan. 1974

Table A-2. Estimated Temperatures from LaVerkin Hot Springs, Utah

Source (1)	Sodium (ppm)	Potassium (ppm)	Calcium (ppm)	Number of samples	Average (2) estimated temperature °C	Range	Comment
Spring discharge	2407	206	823	10	186	181-193	
Spring discharge	2424	203	837	10	185	180-192	
Spring discharge	2325	192	810	10	184	180-190	
Spring discharge	2419	199	828	11	184	181-192	
Spring discharge	2466	194	797	3	183	182-184	
Spring discharge	2464	195	810	3	183	181-184	
Spring discharge	2432	191	816	5	182	181-184	
Spring discharge	2327	206	799	9	188	181-192	
Spring discharge	2466	195	798	3	183	181-185	
Spring discharge	2360	194	852	4	183	181-189	
Spring discharge	2228	182	844	4	182	180-188	
Spring discharge	2259	177	808	4	181	168-185	
Spring discharge	2391	196	824	9	184	180-192	
Virgin River	51	4.2	82	6	36	29-41	400 m upstream
Virgin River	57	4.3	85	6	39	36-44	6 km upstream
Virgin River	932	80	351	8	171	160-193	150 m downstream
Virgin River	370	28	215	5	126	61-164	18 km downstream
160 m Drill Hole	1342	117	661	8	180	169-190	150 m upstream
70 m Drill Hole	2288	226	825	19	194	186-210	At spring
MILLIGAN ET AL. (1966)	2400	230	510	1	198	—	
MUNDORFF (1970)	2415	185	711	4	182	177-191	

(1) Each entry under « Spring discharge » denotes a separate discharge point.

(2) Average of individual estimated temperature and not the temperature estimated from average concentrations.

Source: Geothermics, June 1974

Table A-3. Chemical Analyses of Typical Brines

[Values in p.p.m.]																
Well No.	Na	K	Li	Ca	Mg	Cl	Br	I	Fe	SO ₄	HCO ₃	H ₂ BO ₃	SiO ₂	CO ₂	H ₂ S	Total hardness (as CaCO ₃)
I-A	4,450	690	12	210	30	7,420	5.2	1.0	nd	7.0	52	52	240	nd	nd	699
M-3	5,310	1,160	17	310	11	9,680	10.0	2.8	0.2	15.0	60	55	480	680	218	820
M-5	5,820	1,570	19	280	8	10,420	14.1	3.1	1.2	0	73	71	740	1,620	700	733
M-6	5,000	504	11	388	33	9,000	12.6	2.5	nd	16.4	158	21	151	420	37	1,106
M-7	5,250	910	13	230	18	9,310	8.2	2.6	nd	3.4	71	32	330	940	150	649
M-8	6,100	1,860	17	320	6	11,750	14.3	3.2	nd	0	890	115	770	nd	nd	1,620

¹ From ORNL report cited.

² Hex states that samples M-5 and M-8 are the most probable compositions of normal production of brine.

B. ECONOMIC SCENARIOS

Table B-1 summarizes alternative economic scenarios for the Total Energy Recovery System for Agribusiness based on yield and price ranges discussed in the subsystem portions of this report.

Table B-1
TERSA Economic Scenarios

<u>Activity</u>	<u>Yields*</u>		
	<u>High</u>	<u>Selected</u>	<u>Low</u>
Tomatoes	45,000	40,500	36,000
Cucumbers	40,500	36,000	28,800
Mushrooms	81,000	81,000	81,000
Prawns	24,000	13,500	13,500
<u>Activity</u>	<u>Prices**</u>		
	<u>High</u>	<u>Selected</u>	<u>Low</u>
Tomatoes	\$0.63	\$0.50	\$0.45
Cucumbers	\$0.52	\$0.45	\$0.45
Mushrooms	\$0.85	\$0.75	\$0.75
Prawns	\$4.00	\$4.00	\$3.00
<u>Activity</u>	<u>Incomes</u>		
	<u>High</u>	<u>Selected</u>	<u>Low</u>
Tomatoes	\$28,350	\$20,250	\$16,200
Cucumbers	\$21,060	\$16,200	\$12,960
Mushrooms	\$68,850	\$60,750	\$60,750
Prawns	\$96,000	\$54,000	\$40,500
TOTALS	\$214,260 =====	\$151,200 =====	\$130,410 =====

*in pounds

**in dollars per pound

Based on the above incomes and expenses of \$67,900 annually, the rates of return to the nearest percent on the non-site capital investment for seventeen years for the three cases are: thirty-four percent for the case of high yields and prices; eighteen percent for the case selected for this report; and thirteen percent for the case of low yields and prices.

These scenarios permit calculation of the amount that can be paid in dollars per million Btu for well and land for TERSA to break even on capital investment. This amount is also a function of the rate of interest used in calculating the discounted cash flow present value of net income and is summarized in Table B-2 for seventeen years and varying interest rates.

Table B-2
Breakeven Cost of Energy
(Dollars per Million Btu)

<u>Interest Rate</u>	<u>High</u>	<u>Selected</u>	<u>Low</u>
7%	\$1.12	\$0.43	\$0.20
8%	\$1.02	\$0.37	\$0.16
10%	\$0.83	\$0.27	\$0.08
12%	\$0.69	\$0.18	\$0.02

C. ACKNOWLEDGEMENTS

The assistance of the following in the realization of this report is gratefully acknowledged.

ERDA Program Coordinator:
Marilyn Eggers.

ERDA Technical Consultants:
Jack Angevine, Lawrence Berkeley Laboratory; Syd Willard, California Energy Resources Conservation and Development Commission.

IECO Administration:
R.B. Christensen; R.J. Eveld; K. Kawahata.

IECO Employees:
Myra Sinclair-Smith; Tina Pereira; Dick Fromm; Fred Nakamura; Jim Dimitrov; Ho Lee; Won Suck Byun; Linda Haggerston; Don Guisti; Rose Imazumi; Lee Hannah; Mary Claycomb; Jim Henderson.

Other Individuals:
Seward Besemer; Bill Chalkley; Takuji Fujimura; John Glude; Eugene Grabbe; Beverly Hall; Ray Hasek; Hunter Johnson; Leon Kneebone; Allen Knight; John Lund; Robert Mariner; C.E. Mumaw; Jack Norlyn; Robert Shleser; Tom Wright.

Individuals Representing Organizations:
G. Battencourt, Carrier Corp.; Charles Boomer, Roper IBG; James Breese, Patterson-Kelley Co.; Charles Buckley, Amertap Corp.; Gerhard Foerster, American M.A.N. Corp.; J.L. Kaiser, Pfaudler Co.; Pete Knezevich, Industrial Power Co. (Aerco); Ronald MacQuarrie, C.H. Bull Co.; R. Shuman, Trane Co.

Other Organizations:
Aluminex Incorporated; Castle and Cook; Dome East Corporation; EG&G Idaho, Inc.; Engineers and Fabricators Co.; Everlite Aluminum Greenhouses, Inc.; Lord and Burnam; Rough Brothers; Wayne Floral Co., Inc.; Warren-Sherer.

Institutions:
Anuenue Fisheries Research Center, Hawaii; Geothermal Resources Council; Hawaii Department of Planning and Economic Development; Idaho National Engineering Laboratory; National Marine Fisheries Service; Oregon Institute of Technology Geo-Heat Utilization Center; Pennsylvania State University; United States Geologic Survey, Menlo Park; University of California Agricultural Extension; University of California at Davis and Riverside.

with apologies for omissions.