Feasibility of introducing solar-powered irrigation on a representative Arizona farm

FEASIBILITY OF INTRODUCING SOLAR-POWERED IRRIGATION ON A REPRESENTATIVE ARIZONA FARM

by

Charles Lutge Towle, Jr.

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 6

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Charles J. Towle, Jr.

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

J. C. Day
J. C. DAY
Associate Professor of
Agricultural Economics

November 1, 1976
Date

ACKNOWLEDGMENTS

I wish to acknowledge the efforts of my major professor, John C. Day, whose very careful reviews and meticulous comments contributed much to the completeness of this thesis. I also thank Dr. Reuben N. Weisz, who started me on this effort and Dr. Dennis L. Larson, who provided both moral and financial support to me. Those serving on my orals committee were Dr. Roger W. Fox and Dr. Robert C. Angus. Drs. Day, Fox and Angus are members of the Department of Agricultural Economics and Dr. Larson of the Department of Soils, Water and Engineering at The University of Arizona. Dr. Weisz is with the Economic Research Service, U. S. Department of Agriculture.

In constructing the representative farm of Chapter II, I was assisted immeasurably by the expertise and experience of Dr. Scott Hathorn, Jr. and Mr. Charles Robertson of The University of Arizona Farm Management Office. Others contributing to this effort were Dr. C. Curtis Cable, Dr. Robert S. Firch and N. Gene Wright of the Department of Agricultural Economics and Allen D. Halderman, Agricultural Engineering Specialist, all of The University of Arizona. Many unattributed facts and opinions about Pinal County and Arizona farming and irrigation are from informal discussions with these gentlemen during the spring and summer of 1976.

I would also like to thank Carol J. Schwager and Ginger L. Garrison for decrypting and typing my several drafts and Paula Tripp for her very professional job in typing the final copy of this thesis.

Finally, I would like to acknowledge the many contributions of Charles D. Sands II a fellow researcher at The University of Arizona trying to shed some sunlight on solar-electric power.

I dedicate this thesis to the memory of my mother, Jeanne B. Towle, who passed on during its preparation.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF ILLUSTRATIONS

ABSTRACT

Arizona agriculture is a major consumer of energy. The use of solar power to pump groundwater would free Arizona farmers from reliance on uncertain energy supplies. Using a representative farm model, the economically feasible upper limit for initial investment in solar equipment is derived for alternative pumping situations on a Pinal County farm. A typical value for this figure is $404,000. Solar-powered irrigation systems are estimated to cost about $1.6 million in the representative farm application, four times their justified level to the farm. A surrogate price for solar electricity can be derived from the system cost estimate; this turns out to be 50 mills/kwh in 1976 dollars. The representative farm is currently able to purchase electricity at the low rate of 12 mills/kwh. It is estimated that at best it will take about 40 years for the price of conventional electrical energy to rise enough relative to the general economy to justify the farm paying this price.

CHAPTER I

INTRODUCTION AND BACKGROUND

Arizona's farmers stand in unique relationship to water and energy among the nation's farmers. The employment of large quantities of water and energy is both the source of their Herculean productivity and their Achilles heel. This study will examine through a representative farm feasibility approach the possibility of improving the long-term Arizona crop industry outlook in the face of increasing energy scarcity by using solar energy as the power source for irrigation wells.

Arizona Agriculture -- Water and Energy

Table 1 summarizes the relationship of Arizona production to U. S. production for cotton, wheat, and alfalfa.[1] While Arizona is not a large producing state, it is a most productive state in terms of crop yields per acre. In wheat production in 1974, Arizona outproduced the next closest state by 14 bushels to the acre; in cotton production in 1974, it stood 200 pounds to the acre above its next closest rival; and in hay production, outdistanced all other state productions by 1.3 tons per acre (U. S. Department of Agriculture, 1976, Tables 6, 75, 377). These are not small differences; at 1974 seasonal average prices these yields amounted to gross competitive advantages for these three crops of

1. These three crops account for 58% of cash receipts from marketing of Arizona crops. The other big contributor to Arizona cash receipts is vegetables (18%).

Table 1. Comparison of U. S. and Arizona Crop Production.

Crop	Thousands of Acres Harvested			Yield Per Acre		
	1972	1973	1974	1972	1973	1974
WHEAT						
Arizona	170	216	235	67.0 bu/ac	70.0	66.0
U. S.	47,284	53,869	65,459	32.7 bu/ac	31.7	27.4
COTTON						
Arizona	271	276	392	1,067 lb/ac	1,063	1,218
U. S.	12,888	11,887	12,464	507 lb/ac	521	441
HAY						
Arizona	259	260	255	5.30 tn/ac	5.84	5.93
U. S.	59,821	62,099	60,546	2.15 tn/ac	2.17	2.10

Source: U. S. Department of Agriculture, 1976.

$43.00, $88.00, and $72.80 per acre, respectively, over the next best state in productivity.

There are two major reasons Arizona farmers produce at such prodigious levels. First, the large solar flux the state receives promotes rapid plant growth, and second, practically all Arizona's crops are produced completely under irrigation. Because of the extensive use of irrigation, satisfaction of the biological water needs of Arizona crops is assured. Arizona farmland under irrigation doubled from 0.6 million acres in 1939 to 1.2 million acres in 1959 and has remained at about 1.2 to 1.4 million acres for the past twenty years (U. S. Department of Agriculture, 1976, Table 590). In 1969, there were roughly 2,800 irrigated farms in Arizona, 1,500 farms with 1,000 or more irrigated acres. Over half of the total irrigated acreage is on farms that contain 1,000 acres or more; the average number of irrigated acres on these large farms is 2,150 acres (U. S. Department of Commerce, 1973, Table 5).

Arizona's income from crop production in 1974 was $613 million (preliminary figure, U. S. Department of Agriculture, 1976, Table 590). This gave the Arizona crop production industry about the same level of importance as tourism as a component of state income. Direct employment in Arizona agriculture in 1974 was estimated at 32,000 persons of which about 26,000 are in the hired labor category (U. S. Department of Agriculture, 1976, Table 590).

Rainfall in Arizona's crop growing regions, roughly the southwestern half of the state, typically ranges close to 10 inches per year. Most of this rain falls during the summer in intense, highly localized monsoon storms. Evapotranspiration, the combination of evaporation and plant transpiration, is some four or more times the typical rainfall levels.

Groundwater Use

According to the Arizona Bureau of Mines (1969, p. 592) and the Arizona Water Commission (1975, p. 16), Arizona has a gross water use of about 7.2 million acre-feet (MAF) annually of which about 6.4 to 6.8 MAF is consumed in agriculture. Roughly one-third of Arizona's gross water use is supplied by surface water; the remaining 5 MAF of water is supplied by groundwater pumpage of which about 2.2 to 2.5 MAF represents overdraft. Of the 5 MAF of groundwater pumpage, about 4.7 MAF is for irrigation. Of this 4.7 MAF, perhaps as much as 3.6 MAF is supplied by on-farm wells. The Arizona Water Commission (1975) estimates that through 1973, 150 MAF of groundwater had been mined in Arizona with most of the pumping taking place since 1940.

Energy Use

The amount of energy used for pumping groundwater in Arizona annually is of some interest. It can be roughly estimated as follows.

The amount of water pumped and the amount of energy used in pumping that water can be related to one another by a simple physical constant. Energy is generally thought of as the ability of a substance to perform work and is measured most basically as force exerted over distance. Here we will use as the basic unit of energy the force needed to lift an acre-foot of water (a volumetric measurement that can be easily converted to weight) one foot in height, that is, the acre-foot-foot. Expressed in units of killowatt-hours (to measure electrical energy) one acre-foot-foot is equivalent to 1.024 kwh.

Because of efficiency losses in the motor and pump section of a well more than the ideal 1.024 kwh of energy is required to perform an acre-foot-foot of useful work. Overall pumping efficiencies for electric-powered wells in Arizona typically vary quite widely but a typical figure might be about .57. At this efficiency, 2 kwh of energy must be input to output 1 acre-foot-foot of water (2 kwh = 1.024 kwh/.57).

Table 2 shows the estimated 1975 total groundwater pumpage by region, approximate mean depths-to-water in each region, and the resultant potential energy. From these figures, the total acre-foot-feet of electrical energy equivalent Arizona pumpage can be computed, viz., 1.11 x 10^9 acre-foot-feet of energy were expended in Arizona in 1975 in pumping groundwater. About 90% of this quantity (1.0 x 10^9 acre-foot-feet) is used for irrigation, the balance going for municipal and industrial uses. If the pumpage average efficiency in Arizona is in fact .57, the electrical energy equivalent of one million acre-foot-feet is 2 x 10^9 kwh. Frank (1975) estimates Arizona's total electrical energy use at about 22 x 10^9 kwh. Thus, if Arizona's farmers were pumping groundwater with only electric powered pumps, they would account for an electrical energy use equal to from 8% to 10% of the total state electrical usage.

It is very important to note that this figure is the total energy used in pumping groundwater expressed in electrical energy unit equivalents. Actually only about two-thirds of Arizona's wells are electric powered. Because efficiencies connected with pumping with other forms of energy are lower, the actual total energy used on-the-farm in

Table 2. Energy Used in Pumping Groundwater in Arizona.[a]

Region	Pumpage (thousands of acre-feet)	Approximate Mean Depth (1975) (feet)	Potential Energy of Pumping (acre-feet-feet X 10^3)
Duncan	25	50	1,250
Safford	130	50	6,500
San Simon	100	200	20,000
Willcox	300	250	75,000
Douglas	90	150	13,500
San Pedro	90	100	9,000
Upper Santa Cruz	250	175	43,750
Avra	150	325	48,750
Lower Santa Cruz	800	325	260,000
Salt River Valley	1,800	250	450,000
Waterman	60	350	21,000
Gila Bend Basin	240	150	36,000
Harquahala	110	375	41,250
McMullen	110	300	33,000
Gila River, Painted Rock	130	100	13,000
Ranegras Plain	20	125	2,500
Wellton-Mohawk	200	25	5,000
Yuma	260	75	19,500
Colorado River, Davis-Imperial	20	75	1,500
Sacramento Valley	5	500	2,500
Big Chino Valley	5	300	1,500
Little Chino Valley	10	100	1,000
Williamson Valley	10	200	2,000
Others	100	100	10,000
TOTAL	5,015		1,109,500

a. The statewide typical lift is 220 feet. These estimates were compiled by Morin (1976).

groundwater pumping would be higher, but at the same time one would have to consider the energy efficiency electrical utilities are able to achieve in generating the electricity in the first place to get a true picture of total energy consumed in pumping groundwater in Arizona. The above figure, then, is only a rough estimate, but does serve to indicate the potential impact of the widespread use of solar power for irrigation pumping to Arizona and the close tie between the Arizona crop production industry and the state's energy demand.

Statement of Problem

United States research and development efforts aimed at using the radiation of the sun as a source of inexhaustible energy are not far advanced for applications other than space and water heating. This is so despite the wide currency in the U. S. of solar power concepts and national concerns about energy supply. Arizona farms would seem to make a logical place for early application of power-generating solar systems. Because of their need to pump irrigation water, they require fairly large amounts of power, they generally have sufficient land to support a solar installation, and they enjoy an abundance of sunshine. Presently, however, there are no solar-powered systems that could generate energy in sufficient quantity for the irrigation wells of the sizes found in Arizona. Such systems are not even at the design stage although this work is ongoing. Solar systems for electrical power generation exist mainly as simple conceptual block diagrams showing major subsystem component arrangements. Component development and testing, however, is underway at a number of institutions across the country, including The University of Houston.

Objective

The major objective of this thesis is to estimate the economic investment limits on solar power systems applied to pumping groundwater for crop irrigation. These limits will be derived for a representative Arizona farm. The amount the representative farm could afford to invest, *ceterus paribus*, in a solar system that freed it from dependency on power purchases will be computed. These economically justifiable limits are presented in Chapter III. While computing these limits other parameters useful in judging solar system designs will be derived. It is hoped that the more clearly defined economic bounds on solar system design developed here will contribute to more purposeful solar system engineering effort.

Another objective of this thesis is to estimate the feasibility of solar-powered pumping in the light of current electricity prices. Projected increases in the price of electricity will be examined to form an estimate of when solar-powered pumping might become economically feasible. Both of these estimates will be made using the preliminary solar system concepts and cost estimates available in the summer of 1976. Some alternative solar and irrigation system adaptations will be discussed but not analyzed. From this presentation a better understanding of the close relationship among water, energy, production and revenues of Arizona farms should be attained.

Procedure

Pinal County Background

This study will assess the feasibility of using solar power to pump groundwater based on "representative" farm budgets. To derive specific parameters needed to characterize this farm, it was necessary to imagine it as being in a specific region. The region chosen is Pinal County. The Pinal County agricultural region, viz., the western half of the county, is located along a line between Phoenix and Tucson. It predominantly grows field crops. In 1975, 283,300 acres of crops were harvested, roughly 20% of the Arizona total. Cash receipts to crop enterprises came to $105 million, 17% of the Arizona total (Arizona Crop and Livestock Reporting Service, 1976).

The agricultural producing region in Pinal County is in the Lower Santa Cruz groundwater basin. The Arizona State Water Commission in their Phase I report estimates 48.8 MAF to be in storage in this basin to a depth of 700 feet (Arizona Water Commission, 1975). Annual depletion of this stock due to agricultural use is 748,000 acre-feet, and total annual depletion is 763,000 acre-feet. Total agricultural withdrawal is estimated by the Water Commission at 1.1 MAF. Estimated total pumpage in Pinal since 1915 is 35.5 MAF. Pumping depths have been falling at greatly varying rates across the county; the Arizona Water Commission puts the average annual decline at 8.1 feet/year. There are more than 1,000 irrigation wells in the region.

Conventional Energy Sources Used in Pumping

Four conventional energy sources are used to power irrigation wells in Arizona: natural gas, diesel fuel, LP gas, and electricity. Hathorn (1976) has examined the economics of using each of these energy sources in Pinal County. He concluded that in general when total pumping costs per acre-foot of water are ranked in ascending order of magnitude, natural gas is the most economical energy source, followed in order by electricity, diesel and LP gas. Natural gas and electricity appear to be quite close competitors for best conventional energy source (see Figure 1).

For this study it was decided to pick one conventional energy source as a defender against which solar power would be compared. The energy source selected as the best conventional energy competition for solar systems was electricity supplied from off the farm. Natural gas was rejected because of the great likelihood that in the near future its price will undergo rapid increases due to complete or partial deregulation by the Federal Power Commission as well as to rapidly depleting supplies. These price rises would make it uneconomic compared with electricity. Further, if natural gas is not deregulated, some method of rationing the gas other than the marketplace will certainly be found, making its availability to farms very uncertain. On the other hand, owing to increasing reliance on coal and nuclear power, electricity supplied by large utilities seems likely to become even more predominant as the energy source for stationary uses for the next half century. Most pumping in Pinal is done with electric powered pumps, but precise

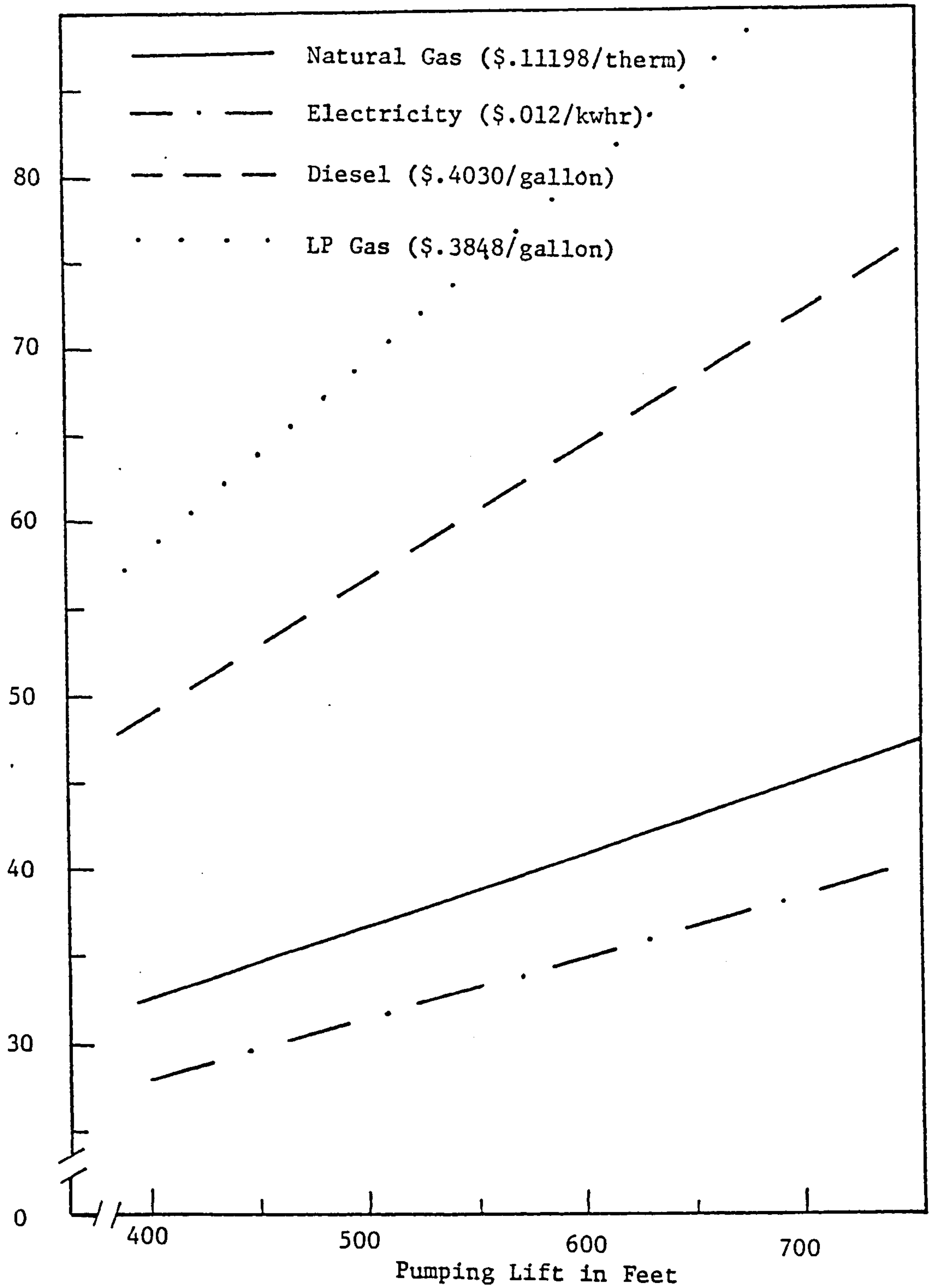

Figure 1. Total Cost (Fixed Plus Variable) of Pumping One Acre-foot of Water by Source of Energy for Selected Pumping Lifts, Eloy Area, Pinal County, 1976 (from Hathorn, 1976).

estimates of the proportion of wells powered by each conventional energy type are not available.

Analysis

Deciding on the economically justifiable level of investment in solar equipment poses the classic problem of balancing a large and immediate capital investment against a stream of less costly but longer lasting outlays. In particular, in this case the investment needed for a solar plant must be balanced against a stream of unending electricity bills. There are two ways to approach the problem of making these two cost situations comparable. Both are based on the well-known concept that economic value of a payment declines the farther into the future it is realized, i.e., on discounting techniques. The two approaches are either to convert the capital cost of the solar plant to a stream of annual payments and compare these to electricity bills or to convert the stream of electricity bills to a present worth that represents the justified level of investment in the capital equipment. Both approaches are conceptually the same but do result in different points-of-view toward the problem, the former approach emphasizing the annualized costs of the system and the latter the investment cost.

Because both discounting approaches are useful, they are both used in this thesis. The emphasis, however, is on delineating the justified level of investment in the solar plant. There are two reasons for this emphasis. The first has to do with the quality of the data available for the respective computations. Stated simply, one can place much more confidence in the precision of the estimates derived here for the representative-farm electricity bills than in the later estimates of the investment costs involved in a solar plant. Thus, one has more confidence in the estimates of justified level of investment (derived in Chapter III) than in the estimates of electricity price rises (electric bills) that must occur in order for solar power to be feasible (as given in Chapter IV).

The second reason for emphasizing justified level of solar plant cost over annualized cost is, in line with the thesis objective, to make the results of the thesis as useful as possible to those currently involved in designing actual solar-energy hardware for irrigation pumping systems. There is currently, as will be clear after reading this thesis, no single accepted way of doing the solar pumping job. With parameterized levels of permitted investment in solar equipment, the solar system designer is given useful key economic information that does not become inapplicable if he should conceive of a way other than that assumed here to accomplish the basic task of ending the purchases of off-the-farm electricity. All he must do is accomplish this task within the investment ceilings derived. To derive an annualized cost, on the other hand, one must first assume a certain solar pumping system configuration. Price information seems most useful to the task of predicting when solar pumping might be feasible, a question of interest not so much to solar system designers as to development managers.

The justifiable investment for an operating solar power system will, then, be uncovered through use of the representative farm budgeting technique. The main economic effect of pumping groundwater with a solar power system is to reduce the amount the farm pays for power by the amount needed to pay for the electricity that will now be produced on the farm. In the first step in this process, then, the amount of potential savings possible in electricity bills will be isolated. The representative farm model will be intentionally structured to picture the direction in which Pinal farm crop patterns and technology seem to be evolving rather than their current (static) position.

In Chapter III, the electricity cost savings will be used to derive the actual investment levels permitted for different values of pumping efficiency, amount of pumping lift, and discount rates. This will be done by finding the present worth of the stream of electricity bills, which is equivalent to the justified investment level. The fixing of capital limits on solar investment is somewhat complicated because part of the solar system equipment, the part that gathers and concentrates the incoming solar energy, called the collector, will have a definitely shorter operating life than the other, electrical generating, solar system components. The justified investment must be apportioned between these two sections over the entire planning period, the 30-year life of the generating equipment. This is, again, accomplished through the use of discounting procedures.

In Chapter IV, a basic solar system design will be used to form a cost estimate for the system that would be needed to accomplish the representative farm pumping job. Price estimates will be derived from this cost estimate through the process of finding an annualized cost of electricity and then isolating out electricity prices. Various elements in the operating environment of the representative farm affecting the pumping power demand will be considered to ascertain their effect on the conclusions reached.

Assumptions

Any study that attempts to look into the future necessarily makes numerous assumptions. Generally, one must assume that the socioeconomic environment in the future will remain as it currently exists and that there will be no technological surprises. This means that, for example, there will be no major changes to Arizona groundwater law, that no major new crops or improved plant strains will be introduced in Pinal County, that the position of Arizona farmers in national product markets will neither improve nor grow worse, and so on. Obviously, then, except through sheer good luck the picture of the future given here will not be the one that will in actuality occur. The basis for the predictions have been made sufficiently flexible and broad in this thesis to apply to a great range of situations. It would not be of much use to attempt to catalog here the numerous assumptions that go into a study such as this. The reader is urged to treat these results with the same caution he would treat the results of any similar study that attempts to outline the shape of the future. The most important assumptions to these results will be pointed out as they enter the study.

For now, three points should be made. The first is that the only comparison made in this thesis is that of solar power to conventional electricity. The possibility of an intervening energy technology, for example, that of fuel cells, entering the investment decision picture is ignored. The second point is that it is not clear that the price of energy can rise without directly affecting all other prices in the economy over the long run. Such an independent energy price rise is necessary for solar to be feasible unless there is a major technological breakthrough in solar power. Discovery of a greatly cheaper means of applying solar energy is extremely unlikely. There are energy inputs to all processes in the economy; if the price of energy rises, it would seem not unreasonable to expect that the price of all other outputs would rise correspondingly sooner or later. Of particular concern is the elasticity of the price of the materials that are used in constructing solar equipment with respect to the price of energy. Finally, there is inherent in this thesis with regard to assumptions an unavoidable contradiction. To model the representative farms and form permissible investment estimates socioeconomic constancy is assumed; then, in judging whether solar-power is feasible, major rises in the price of energy are assumed under which socioeconomic constancy is not possible. Despite these limitations, the estimates formed herein should be worthwhile and informative to solar-power designers and managers.

CHAPTER II

DESCRIPTION AND BUDGETING OF THE REPRESENTATIVE FARM

In selecting the parameters which describe the representative farm developed in this study, the following guidelines were used:

1. Farm characteristics should be as close as possible to median characteristics for Pinal County farms.

2. Where time trends in parameter values seem apparent these trends should be incorporated in the values chosen, that is, it should be assumed that the farmer is fairly quick to adapt to new situations.

3. The farmer is a rational and capable manager and grower desiring to maximize profits over the short run and the net worth of his investment over the long run.

4. In parameterizing the representative farm unnecessary detail should be avoided.

Farm Size

Some of the basic data that went into selecting the farm size were given in Chapter I. In particular it should be recalled that just less than 50% of Arizona irrigated acreage on farms earning $2,500 or more is on farms with 1,000 or more irrigated acres.[1] Thus, 1,000 irrigated and cropped acres were chosen as the size for solar farm.

---

1. According to U. S. Department of Commerce (1973), of the 1.13 million acres irrigated in Arizona in 1969, 540,353 acres were on farms with 1,000 or more irrigated acres (Table 5).

(For simplicity the term "solar farm" is used to mean the representative Pinal County farm with potential for converting to solar-pumped irrigation.)

Unpublished data collected from the Eloy area of Pinal County by Firch (1974) show a representative farm as having 1,637 gross acres of which 670 were undeveloped for cropping. Of the 967 acres with potential for immediate production, 637 were actually cropped. Thus, solar farm is somewhat larger than Firch's 1974 representative farm. The reasons for selecting a somewhat larger operation are that the trend in Arizona is to larger, corporation-type farms and that larger farms are also more likely to have the financial assets behind them necessary to obtain the loans for large capital investments such as would be needed for the solar pumping system.

It should be noted that Firch's data indicate that land is most definitely not a constraint on the quantity of crops grown nor would it be a problem for a solar installation. A solar installation of the type that will be described later requires about a 15-acre site. In fact, since some land on solar farm is unemployed, it might be argued that there should be no cost assigned to siting the solar plant since there is no opportunity cost involved in using the land for a solar plant.

Representative Crop Mix

Two main questions must be answered to characterize solar farm with respect to crop patterns. After these questions are answered most of the other farm parameters are simply derivative values. The questions are: Which crops are likely to be grown and in what proportion?

The major crops planted and harvested in Pinal County and their average percentage of total acres harvested over the last eight years are shown in Table 3 and Figure 2.

A definite trend appears to be underway in Pinal from feed grains to food grains. Grain sorghum competes with cotton for water and land during the summer months and does not cover its assignable fixed costs. Hathorn et al. (1976) computes the likely 1976 per acre loss on sorghum at $68.23. Over the long term then, the grain sorghum crop will likely dwindle to unimportance. Barley competes directly for resources with wheat on several dimensions. It requires slightly more water than wheat to satisfy its consumptive needs, but, in its favor, needs this water earlier in the year. Both crops entail basically the same input costs. It is the opinion of Hathorn that wheat will replace barley in Pinal fields because of the greater yield potential of wheat; also, wheat revenues per acre are currently growing much faster than barley's (17.5% vs. 10%) (Arizona Crop and Livestock Reporting Service, 1976). For the solar farm, wheat will be allowed to supplant barley, bearing in mind the two crops are quite similar from the viewpoint of water and other inputs. It was decided that the small acreages of safflower and sugar beets indicated by county statistics would not affect the solar farm results, consequently these crops were not included.

The resulting crop mix chosen for the entire solar farm study is:

Upland Cotton	441 acres
American-Pima Cotton	36 acres
Wheat	416 acres
Alfalfa	107 acres
TOTAL	1,000 acres

Table 3. Pinal County Cropping Pattern, Field Crops.

Crop	Percent of Total Acres	Planting Trend
Upland Cotton	44.1	Steady
Pima Cotton	3.6	Steady
Barley	17.5	Down
Wheat	16.4	Up
Sorghum	7.7	Down
Alfalfa	7.6	Steady
Safflower	1.1	Erratic
Sugar Beets	2.0	Steady

Source: Arizona Crop and Livestock Reporting Service (1976).

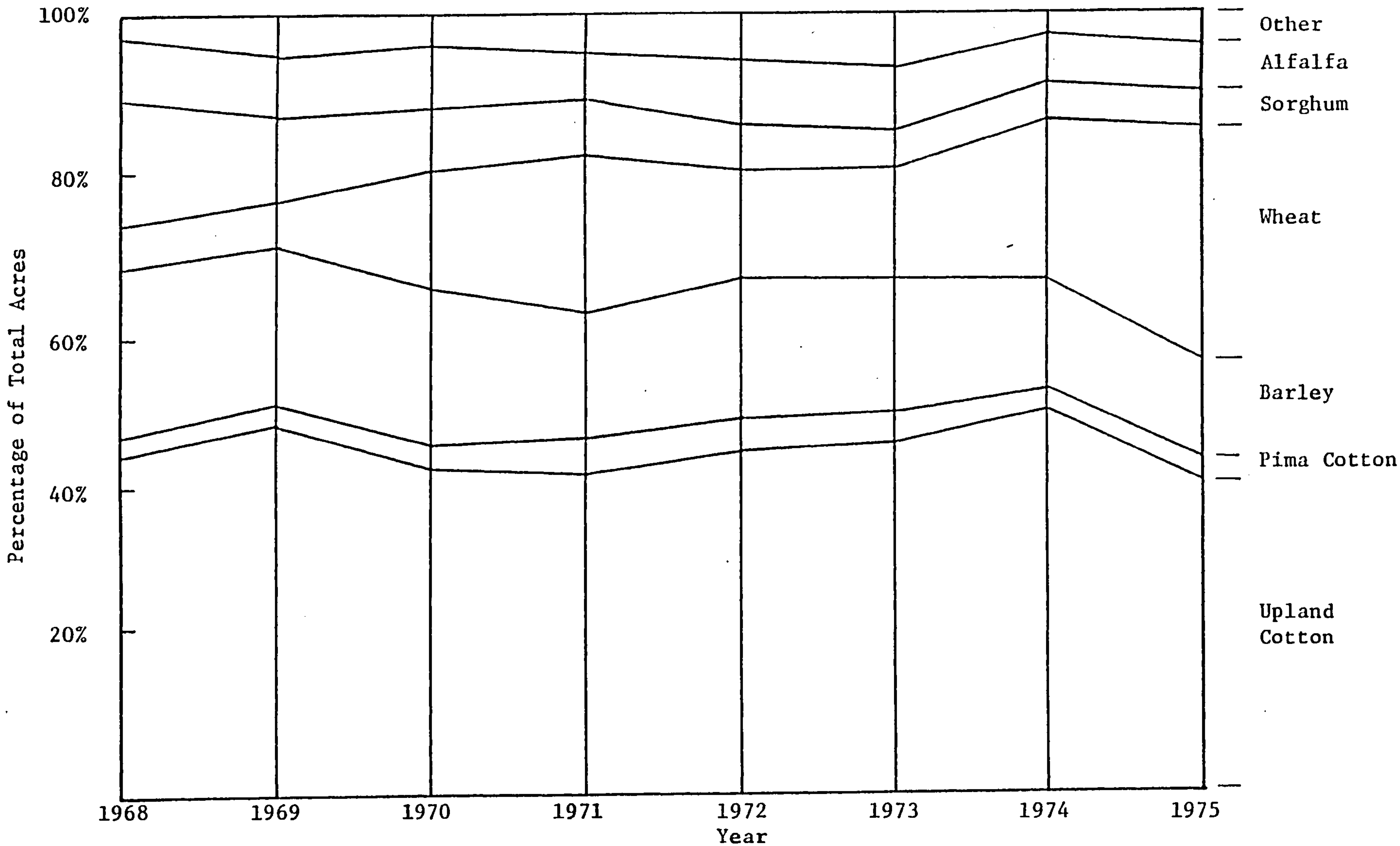

Figure 2. Pinal County Cropping Pattern Trends.

Source: Arizona Crop and Livestock Reporting Service (1976).

Note that wheat was given all the acreages freed by dropping barley and grain sorghum from consideration, while alfalfa picked up the safflower and sugar beet acreages. A possibility exists for double-cropping wheat and cotton, but presently this practice extracts an excessive penalty from the yield of one or the other crop. No double cropping is carried out on solar farm.

Solar Farm Irrigation System

According to classic marginalist economic thinking, the quantity of water applied to a crop should be determined by that point on the water production function where the marginal value product created by applying water equals the price of the marginal unit of water. In reality, the economists idealized water production functions, really n-dimensional models of plant growth and maturation, do not now and probably never will exist.

The location of a few points in the water production n-dimensional space are roughly known. One might derive from these points something resembling the water production curves that production economics theory requires and from these curves derive the amount of water to be used by solar farms at various water prices. For this study the decision is made, however, that it is more realistic to accept the water application rates that Pinal County farmers are using on different crops as given and fixed. The underlying assumption here, viz., a linear relationship between water applied and acres of crop grown, is necessitated by the lack of complete data and the unreliability of such data as do exist.

The total water requirement of solar farm was determined using coefficients that linked acres of crops grown to specific amounts of water applied. Two sources of such coefficients exist. The first source is Arizona Agriculture Experiment Station (1968) which gives plant consumptive need by semimonthly period. These figures establish useful minimums for allocating water by semimonthly periods; however, lacking knowledge of farm water application efficiency, i.e., the percentage of irrigation water delivered from the well that is stored in the soil for consumptive use by crops after allowing for irrigation losses, they are of little value for determining total solar farm pumpage.

In order to determine solar farm pumpage, data from Hathorn et al. (1976) were used. This report is one product of an extensive farm management information system (MIS) that has been developed at The University of Arizona. This MIS is based on data collected from farmers, extension agents, and other experts in the industry infrastructure. The information is updated yearly. One type of information collected from the Pinal budgets is how much water farmers pump for crops and when. It was this information, refined by plant consumptive use data, that was used as the basic water demands on which this report is based.

Tables 4 and 5 show the per acre and total water applications for each of the four crops used in this study for every semimonthly period. Alfalfa production requires 729 acre-feet, cotton 2,396 acre-feet and wheat 1,317 acre-feet annually. The total pumpage required on the solar farm is 4,450 acre-feet. The highest monthly total pumpage is 609 acre-feet in April and the highest semimonthly total is 335 acre-feet in late May. Satisfaction of the semimonthly pumpage requires the greatest

Table 4. Solar Farm Crop Water Application Pattern -- Water Used per Acre in Acre-inches.

Semi-Monthly Period	Alfalfa Establishment[a]	Alfalfa	Upland Cotton	Pima Cotton	Wheat
January					
Early	--	--	12(4)[b]	--	--
Late	--	--	--		8(.5)
February					
Early	--	5	12(.15)	--	--
Late	--	--	12(.15)	12	--
March					
Early	--	5	12(.3)	--	--
Late	--	--	--	--	7.5[c]
April					
Early	--	5	--	--	7.5
Late	--	5	--	--	7.5
May					
Early	--	5	--	--	6
Late	--	5	6	6	1.5
June					
Early	--	6	6	6	--
Late	--	6	6	6	--
July					
Early	--	6	6	6	--
Late	--	6	6	6	--
August					
Early	--	6	6	6	--
Late	--	--	6	6	--
September					
Early	--	5	6	6	--
Late	12(.5)/4(.5)	--	6	6	--
October					
Early	12(.5)	5	--	6	--
Late	4(.5)	--	--	--	--
November					
Early	4(.5)	5	--	--	--
Late	--	--	--	--	--
December					
Early	4(.5)	--	--	--	--
Late	--	--	--	--	8(.5)
TOTALS	20.0	75.0	60.0	66.0	38.0

Table 4. (continued)

a. Alfalfa is a three-year crop; one-third of stand establishment has been charged to each year.

b. "(.X)" indicates proportion of crop irrigated during period.

c. Wheat irrigation shifted toward first half of growing season. No stress of plant should result.

Table 5. Solar Farm Crop Water Application Pattern -- Total Water Used in Acre-feet.

Semi-Monthly Period	Alfalfa Establishment (35.7 acre)	Alfalfa (107 acre)	Upland Cotton (441 acre)	Pima Cotton (36 acre)	Wheat (416 acre)
January					
Early	--	--	176.4[a]	--	--
Late	--	--	--	--	138.7
February					
Early	--	44.6	66.15[a]	--	--
Late	--	--	66.15[a]	36	--
March					
Early	--	44.6	132.3[a]	--	--
Late	--	--	--	--	260.0
April					
Early	--	44.6	--	--	260.0
Late	--	44.6	--	--	260.0
May					
Early	--	44.6	--	--	208.0
Late	--	44.6	220.5	18	52.0
June					
Early	--	53.5	220.5	18	--
Late	--	53.5	220.5	18	--
July					
Early	--	53.5	220.5	18	--
Late	--	53.5	220.5	18	--
August					
Early	--	53.5	220.5	18	--
Late	--	--	220.5	18	--
September					
Early	--	44.7	220.5	18	--
Late	17.8/6.0	--	--	18	--
October					
Early	17.8	44.6	--	--	--
Late	6.0	--	--	--	--
November					
Early	6.0	44.6	--	--	--
Late	--	--	--	--	--
December					
Early	6.0	--	--	--	--
Late	--	--	--	--	138.7
TOTALS[b]	59.6	669.0	2205.0	198	1317.4

Table 5. (continued)

a. Upland cotton pre-irrigation has been scheduled from early January to early March so as to smooth pump demand.

b. The annual total pumpage for the entire farm is 4,449 acre-feet; the highest monthly pumpage is 609 acre-feet for April and highest semi-monthly pumpage is 335 acre-feet in the late May period.

amount of pumping, and so, determines the total well capacity needed on solar farm.

A word of explanation is in order concerning the reason the monthly maximum pumpage occurs in April. The current situation on most Pinal County farms is, of course, that irrigation demand is the highest in the summer since the maximum cotton irrigating requirements occur during this season. Cotton is the major Pinal County crop. For solar farm, however, cotton and wheat production will be, as noted earlier, of about equal importance. Cotton and wheat both require irrigation in late May, and it would be very expensive to build a system to satisfy the Hathorn irrigation schedule for both crops. Fortunately, this problem can be lessened by shifting the wheat irrigation schedule so that this crop is watered more heavily earlier in the year than is the current practice. In fact, judged in terms of satisfying the consumptive need of wheat for water, such a shift from current practice improves the irrigation schedule (see Table 6). Table 6 shows the changes in irrigation schedule made for this study. Since wheat still receives in total as much water as called for by the existing schedule, this adjustment should be costless, and since reducing late May irrigation permits the farmer to get by on a lower well-field capacity, he will be motivated to make such a shift to reduce fixed costs. In the case of solar farm this simple adjustment allows two 1,200 gpm wells to be removed from the farm structure at a saving in capital investment of about $150,000.

Knowing plant water consumptive demands and water supplied, it is possible to derive the irrigation efficiencies implicit in the Hathorn budget (see Table 7). The efficiencies shown in Table 7 for cotton or

Table 6. Revised Irrigation Schedule for Wheat.

	March Late	April Early	April Early	May Early	May Late
Wheat Consumptive Need (acre-in)	3.52	5.25	5.85	4.20	.72
Pinal Existing Budget (acre-in)	6.00	6.00	6.00	6.00	6.00
Solar Revised Budget (acre-in)	7.50	7.50	7.50	6.00	1.50

Table 7. Solar Farm Implicit Irrigation Efficiencies.

Crop	Consumption	Supplied (acre-inches per acre)	Irrigation Efficiency
Upland Cotton	41.2	60	.69
Pima Cotton	41.2	66	.62
Wheat	22.9	38	.60
Alfalfa	74.3	95	.78

wheat are about at the level that would be expected under careful management of losses for furrow irrigation; a present typical level is perhaps .55 (Ozsabuncuoglu, 1976). The high efficiency for alfalfa reflects the fact that the typical Pinal farmer stresses his alfalfa crop during the summer when it competes with cotton for water. This practice results in reduced alfalfa yields.

With the amount and timing of irrigation known, it is possible to work back to the number of wells on the farm. Both Nelson and Busch (1967) in a study of Central Arizona irrigation pumping and the more recent Hathorn (1976) MIS data indicate 1,200 gallons per minute is a typical capacity for Pinal agricultural wells. We assume that the solar farm has sufficient capacity to support the crop plan. The basic crop plan requires a peak load capacity of 335.1 acre-feet of water during the late-May period. There are 16 days in late May, so the wells must be capable of supplying (335.1/16) 20.9 acre-feet/day. To convert acre-feet/day to gallons per minute the conversion factor used is 226.3 gpm/acre-feet/day; 20.9 acre-feet/day represents an irrigation system capacity of 4,730 gallons per minute. Thus, solar farm may use four 1,200 gpm wells to satisfy its crop plan.

Recall from Table 5 that the total water pumped on solar farms annually is 4,449 acre-feet (1.45 billion gallons). Four wells operating continuously for a year at 1,200 gpm can supply 2.52 billion gallons. Thus, the duty factor of the solar farm well system is (1.45/2.52) .575. The duty factor represents the percentage of time the system is operated during the year. It serves as a good index of how erratic equipment use is through the year; that is, the more peaks occurring in a year, the more equipment must be available just to handle peak load and the lower the duty factor. For instance, before the wheat irrigation schedule adjustment referred to earlier in this chapter and consequent reduction in the number of wells was made, the duty factor of the solar farm irrigation system was .383.

The duty factor level conveys additional vital information when considering solar applications. Because a solar power unit is limited by the availability of sunlight, solar equipment is inherently limited to a duty factor of less than a .5 average over the entire year. If the equipment to be operated using solar energy has a duty factor higher than .5, some form of auxiliary energy must be provided or some means of storing the solar energy must be provided. In lieu of either of these alternatives, the amount of equipment must be increased so that the job can be finished during daylight but with a less satisfactory overall usage rate on the equipment. The .575 duty factor for solar farm's wells indicates one of these options must indeed be added to the basic, all solar plant. This matter will be covered in detail in Chapter IV.

All solar farm wells were assumed typically to be working at a 460 foot pumping lift. Typical depths seen in Pinal County farming areas are as follows (Hathorn, 1976):

	Average Lift
Coolidge	395 feet
Casa Grande	555 feet
Eloy	605 feet
Stanfield	610 feet
Maricopa	480 feet

Pumping lift is, of course, one of the most important parameters in this study; it will come in for much consideration later. Here it should be noted that to a good first order approximation, i.e., ignoring local geology, pumping cost and energy expended increase linearly with lift.

Economic Environment for Solar Farm

Prices

We have now derived the necessary physical information about the solar farm, but before we can move on to derive investment levels for solar equipment, we must examine solar farm's basic costs and returns. Before computing the costs and returns for solar farm, the topic of what prices to use in this study must be considered. It will be the general assumption here that the relative price of inputs, save energy inputs, and of outputs will hold a constant relationship to one another into the future. This means that if upland cotton brings, say, half as much as American-Pima cotton in the base period, it will continue to bring half as much as American-Pima throughout the study period. Table 8 presents American-Pima, wheat, and alfalfa season-average prices in Arizona markets for the past five years divided by the price of upland cotton. The ratio values are for pounds of American-Pima and tons of wheat and alfalfa cubes. The ratios appear to be reasonably steady except for American-Pima cotton in 1973 and wheat in 1974.

The position taken here is that the few years in which particular crops have exceptional prices are unimportant for long-term capital analysis. Specific prices and crop yields will be taken from the farm MIS data. The crop yields in the MIS file are 7 tons per acre for

Table 8. Relative Price Ratios for Solar Farm Crops.[a]

Year	American-Pima	Wheat	Cubed Alfalfa	Upland Cotton ($/lb)
1971	1.46	190	130	.2995
1972	1.41	187	144	.2930
1973	2.24	200	123	.4330
1974	1.42	237	143	.4410
1975	1.45	203	132	.5150
BASE VALUE	1.44	203	134	

a. Figures shown are price of crop divided by price of upland cotton.

alfalfa, 1,050 pounds of lint (1,370 pounds of seed)per acre for upland, 538 pounds of lint (877 pounds of seed)[1] per acre for American-Pima, and 2.15 tons per acre for wheat.

Solar Farm Budget

A budget for the solar farm base case described in the preceding pages was prepared using the Arizona farm management information system.

Cost of Water. The first step in budgeting for solar farm is to breakdown the fixed and variable costs of the four wells. To ascertain the cost of carrying great well capacity just to satisfy a few demand periods in the year, the first well is assumed to be supplying as much of the total pumpage as it could, after which the second well would be brought on line, and so on (see Table 9). In this way, the fixed costs of the first well are spread over as much water as possible. The computer-generated budgets for the four wells are shown in Tables 10-13. Note that the assignable fixed cost of the water from the busiest well is $4.32 per acre-foot, rising to $13.24 for the least used well. The fixed cost of all four wells spread over the total amount of water pumped results in an average fixed cost charge of $6.29/acre-foot. The variable cost charge is $14.33/acre-foot, of which $10.87 is paid for energy and $3.46 for operation and maintenance of the well.

Combining the results of the budgets from all four wells gives the following expression for water cost per acre-foot:

Total Well Cost = Fixed Cost Charge of $6.29/acre-foot +

Energy Cost Charge of $10.87/acre-foot +

1. Taylor (1976) recommends seed-to-lint ratios of 1.59 for Upland and 1.63 for American-Pima.

Table 9. Operating Schedule for Solar Farm Wells.[a]

Period	Well #1	Well #2	Well #3	Well #4
January				
Early	15 (100%)	15 (100%)	3.3 (21.9%)	--
Late	16 (100%)	10.2 (63.6%)	--	--
February				
Early	15 (100%)	5.9 (39.3%)	--	--
Late	13 (100%)	6.3 (48.3%)	--	--
March				
Early	15 (100%)	15 (100%)	3.4 (22.5%)	--
Late	16 (100%)	16 (100%)	16 (100%)	1.1 (6.6%)
April				
Early	15 (100%)	15 (100%)	15 (100%)	12.5 (83.1%)
Late	15 (100%)	15 (100%)	15 (100%)	12.5 (83.1%)
May				
Early	15 (100%)	15 (100%)	15 (100%)	2.7 (17.7%)
Late	16 (100%)	16 (100%)	16 (100%)	15.2 (95.2%)
June				
Early	15 (100%)	15 (100%)	15 (100%)	10.1 (67.3%)
Late	15 (100%)	15 (100%)	15 (100%)	10.1 (67.3%)
July				
Early	15 (100%)	15 (100%)	15 (100%)	10.1 (67.3%)
Late	16 (100%)	16 (100%)	16 (100%)	7.1 (44.4%)
August				
Early	15 (100%)	15 (100%)	15 (100%)	10.1 (67.3%)
Late	16 (100%)	16 (100%)	13 (81.3%)	--
September				
Early	15 (100%)	15 (100%)	15 (100%)	8.4 (56.2%)
Late	7.9 (52.6%)	--	--	--
October				
Early	11.8 (78.4%)	--	--	--
Late	1.1 (7.1%)	--	--	--
November				
Early	9.5 (63.6%)	--	--	--
Late	--	--	--	--
December				
Early	1.1 (7.5%)	--	--	--
Late	16 (100%)	10.2 (63.6%)	--	--
Total Days Operated	305.4	246.6	187.7	99.9

Table 9. (continued)

Period	Well #1	Well #2	Well #3	Well #4
Water Pumped	1,618.62	1,306.98	994.81	529.47
Duty Factor	.837	.676	.514	.274
Percent of Total Water Provided	36.4	29.4	22.4	11.9

a. Figures shown are days operated during period to meet water requirement.
15-day capacity = 79.5 acre-feet/well
16-day capacity = 84.8 acre-feet/well
365-day capacity = 1934.5 acre-feet/well
1200 gpm wells supplying 5.3 acre-feet/day

Table 10. Cost of Pumping Water in 1976, Well No. 1.

WELL NO 1 — ELECTRIC POWER — 460 FOOT LIFT

SOLAR FARM BASE CASE — PINAL COUNTY

A. SPECIFICATIONS AND ASSUMPTIONS

1. WELL IS DRILLED AND CASED WITH 16 INCH CASING TO 1500 FEET
2. BOWLS ARE SET AT 500 FEET
3. WELL PUMPS 1200 GPM AND 1619 ACRE FEET ANNUALLY
4. ELECTRICTY COST IS 12.00 MILLS PER KWH
5. OVERALL EFFICIENCY IS 52.0 PERCENT
6. DEPRECIATE WELL 25 YEARS WITH 0 PERCENT SALVAGE
7. DEPRECIATE PUMP ASSEMBLY 25 YEARS WITH 3 PERCENT SALVAGE
9. DEPRECIATE POWER UNIT 25 YEARS WITH 3 PERCENT SALVAGE
8. DEPRECIATE BOWLS 25 YEARS WITH 3 PERCENT SALVAGE
10. COMPUTE INTEREST ON AVERAGE INVESTMENT AT 8.50 PERCENT
11. COMPUTE TAXES ON 18.00 PERCENT OF AVERAGE INVESTMENT USING A TAX RATE OF $10.21 PER $100 ASSESSED VALUATION

B. PRICE QUOTATIONS (INCLUDING 4.0 PERCENT SALES TAX) --- 02/31/76

1.	DRILLING COST AND CASING INSTALLATION	24000.
2.	CASING (INCLUDING PERFORATION)	15251.
3.	PUMP ASSEMBLY (8 INCH COLUMN)	19009.
4.	12 INCH BOWLS (11 STAGES)	3536.
5.	POWER UNIT--- 250 HP MOTOR	6136.
6.	STARTER WITH HAND COMPENSATOR AND SECONDARY POWER STATION WITH SAFETY SWITCH	5302.
7.	INSTALLATION LABOR AND SITE COSTS	1313.
	TOTAL COST OF WELL	74547.

C. ANNUAL FIXED COSTS

DEPRECIATION	2940.
INTEREST	3213.
TAXES	695.
FIRE AND LIGHTNING INSURANCE	154.
TOTAL	7002.

D. WATER COST PER ACRE FOOT

1. FIXED COST = 7002./1619. AF = 4.32
2. VARIABLE COST = (1.024 * 460 * .01200)/.520 + .007512 * 460 = 14.33

WHERE
- 1.024 = KWH TO LIFT 1 AF OF WATER 1 FOOT AT 100 PERCENT OVERALL EFFICIENCY
- 460 = FEET OF LIFT
- .01200 = POWER COST PER KWH INCLUDING SALES TAX
- .520 = OVERALL EFFICIENCY STATED AS A DECIMAL FRACTION
- .007512 = COST OF PLANT REPAIRS, MAINTENANCE, LUBRICATION AND ATTENDANCE PER FOOT OF LIFT

3. TOTAL COST = 18.65

E. KWH OF ELECTRICITY USED TO PUMP 1 AF = 905.85 1619 AF = 1466565.

Table 11. Cost of Pumping Water in 1976, Well No. 2.

WELL NO 2 — ELECTRIC POWER — 460 FOOT LIFT

SOLAR FARM BASE CASE — PINAL COUNTY

A. SPECIFICATIONS AND ASSUMPTIONS

1. WELL IS DRILLED AND CASED WITH 16 INCH CASING TO 1500 FEET
2. BOWLS ARE SET AT 500 FEET
3. WELL PUMPS 1200 GPM AND 1307 ACRE FEET ANNUALLY
4. ELECTRICTY COST IS 12.00 MILLS PER KWH
5. OVERALL EFFICIENCY IS 52.0 PERCENT
6. DEPRECIATE WELL 25 YEARS WITH 0 PERCENT SALVAGE
7. DEPRECIATE PUMP ASSEMBLY 25 YEARS WITH 3 PERCENT SALVAGE
9. DEPRECIATE POWER UNIT 25 YEARS WITH 3 PERCENT SALVAGE
8. DEPRECIATE BOWLS 25 YEARS WITH 3 PERCENT SALVAGE
10. COMPUTE INTEREST ON AVERAGE INVESTMENT AT 8.50 PERCENT
11. COMPUTE TAXES ON 18.00 PERCENT OF AVERAGE INVESTMENT USING A TAX RATE OF $10.21 PER $100 ASSESSED VALUATION

B. PRICE QUOTATIONS (INCLUDING 4.0 PERCENT SALES TAX) --- 02/31/76

1. DRILLING COST AND CASING INSTALLATION	24000.
2. CASING (INCLUDING PERFORATION)	15251.
3. PUMP ASSEMBLY (8 INCH COLUMN)	19009.
4. 12 INCH BOWLS (11 STAGES)	3536.
5. POWER UNIT--- 250 HP MOTOR	6136.
6. STARTER WITH HAND COMPENSATOR AND SECONDARY POWER STATION WITH SAFETY SWITCH	5302.
7. INSTALLATION LABOR AND SITE COSTS	1313.
TOTAL COST OF WELL	74547.

C. ANNUAL FIXED COSTS

DEPRECIATION	2940.
INTEREST	3213.
TAXES	695.
FIRE AND LIGHTNING INSURANCE	154.
TOTAL	7002.

D. WATER COST PER ACRE FOOT

1. FIXED COST = 7002./1307. AF = 5.36
2. VARIABLE COST = (1.024 * 460 * .01200)/.520 + .007512 * 460 = 14.33

   WHERE 1.024 = KWH TO LIFT 1 AF OF WATER 1 FOOT AT 100 PERCENT OVERALL EFFICIENCY
   460 = FEET OF LIFT
   .01200 = POWER COST PER KWH INCLUDING SALES TAX
   .520 = OVERALL EFFICIENCY STATED AS A DECIMAL FRACTION
   .007512 = COST OF PLANT REPAIRS, MAINTENANCE, LUBRICATION AND ATTENDANCE PER FOOT OF LIFT

3. TOTAL COST = 19.69

E. KWH OF ELECTRICITY USED TO PUMP 1 AF = 905.85 1307 AF = 1183941.

Table 12. Cost of Pumping Water in 1976, Well No. 3.

```
   WELL NO   3                 ELECTRIC POWER                       460 FOOT LIFT
   SOLAR FARM BASE CASE              PINAL COUNTY
---------------------------------------------------------------------------------
A.   SPECIFICATIONS AND ASSUMPTIONS

      1.  WELL IS DRILLED AND CASED WITH 16 INCH CASING TO 1500 FEET
      2.  BOWLS ARE SET AT 500 FEET
      3.  WELL PUMPS 1200 GPM AND   995 ACRE FEET ANNUALLY
      4.  ELECTRICTY COST IS 12.00 MILLS PER KWH
      5.  OVERALL EFFICIENCY IS 52.0 PERCENT
      6.  DEPRECIATE WELL 25 YEARS WITH   0 PERCENT SALVAGE
      7.  DEPRECIATE PUMP ASSEMBLY 25 YEARS WITH   3 PERCENT SALVAGE
      9.  DEPRECIATE POWER UNIT 25 YEARS WITH   3 PERCENT SALVAGE
      8.  DEPRECIATE BOWLS 25 YEARS WITH   3 PERCENT SALVAGE
     10.  COMPUTE INTEREST ON AVERAGE INVESTMENT AT   8.50 PERCENT
     11.  COMPUTE TAXES ON 18.00 PERCENT OF AVERAGE INVESTMENT USING
             A TAX RATE OF $10.21 PER $100 ASSESSED VALUATION

B.   PRICE QUOTATIONS (INCLUDING  4.0 PERCENT SALES TAX) --- 02/31/76

      1.  DRILLING COST AND CASING INSTALLATION                       24000.
      2.  CASING (INCLUDING PERFORATION)                              15251.
      3.  PUMP ASSEMBLY ( 8 INCH COLUMN)                              19009.
      4.  12 INCH BOWLS (11 STAGES)                                    3536.
      5.  POWER UNIT--- 250 HP MOTOR                                   6136.
      6.  STARTER WITH HAND COMPENSATOR AND                            5302.
             SECONDARY POWER STATION WITH SAFETY SWITCH
      7.  INSTALLATION LABOR AND SITE COSTS                            1313.

                TOTAL COST OF WELL                                    74547.

C.   ANNUAL FIXED COSTS

          DEPRECIATION                              2940.
          INTEREST                                  3213.
          TAXES                                      695.
          FIRE AND LIGHTNING INSURANCE               154.

                TOTAL                               7002.

D.   WATER COST PER ACRE FOOT

      1.  FIXED COST         =    7002./ 995. AF  =   7.04

      2.  VARIABLE COST      =   (1.024  * 460  * .01200)/.520 + .007512 * 460
                             =     14.33

           WHERE    1.024    =   KWH TO LIFT 1 AF OF WATER 1 FOOT AT 100
                                    PERCENT OVERALL EFFICIENCY
                      460    =   FEET OF LIFT
                   .01200    =   POWER COST PER KWH INCLUDING SALES TAX
                     .520    =   OVERALL EFFICIENCY STATED AS A DECIMAL FRACTION
                  .007512    =   COST OF PLANT REPAIRS, MAINTENANCE, LUBRICATION
                                    AND ATTENDANCE PER FOOT OF LIFT

      3.  TOTAL COST         =    21.37

E.   KWH OF ELECTRICITY USED TO PUMP   1 AF =  905.85       995 AF =    901317.
---------------------------------------------------------------------------------
```

Table 13. Cost of Pumping Water in 1976, Well No. 4.

WELL NO 4 ELECTRIC POWER 460 FOOT LIFT

SOLAR FARM BASE CASE PINAL COUNTY

A. SPECIFICATIONS AND ASSUMPTIONS

1. WELL IS DRILLED AND CASED WITH 16 INCH CASING TO 1500 FEET
2. BOWLS ARE SET AT 500 FEET
3. WELL PUMPS 1200 GPM AND 529 ACRE FEET ANNUALLY
4. ELECTRICTY COST IS 12.00 MILLS PER KWH
5. OVERALL EFFICIENCY IS 52.0 PERCENT
6. DEPRECIATE WELL 25 YEARS WITH 0 PERCENT SALVAGE
7. DEPRECIATE PUMP ASSEMBLY 25 YEARS WITH 3 PERCENT SALVAGE
9. DEPRECIATE POWER UNIT 25 YEARS WITH 3 PERCENT SALVAGE
8. DEPRECIATE BOWLS 25 YEARS WITH 3 PERCENT SALVAGE
10. COMPUTE INTEREST ON AVERAGE INVESTMENT AT 8.50 PERCENT
11. COMPUTE TAXES ON 18.00 PERCENT OF AVERAGE INVESTMENT USING A TAX RATE OF $10.21 PER $100 ASSESSED VALUATION

B. PRICE QUOTATIONS (INCLUDING 4.0 PERCENT SALES TAX) --- 02/31/76

1.	DRILLING COST AND CASING INSTALLATION	24000.
2.	CASING (INCLUDING PERFORATION)	15251.
3.	PUMP ASSEMBLY (8 INCH COLUMN)	19009.
4.	12 INCH BOWLS (11 STAGES)	3536.
5.	POWER UNIT--- 250 HP MOTOR	6136.
6.	STARTER WITH HAND COMPENSATOR AND SECONDARY POWER STATION WITH SAFETY SWITCH	5302.
7.	INSTALLATION LABOR AND SITE COSTS	1313.
	TOTAL COST OF WELL	74547.

C. ANNUAL FIXED COSTS

DEPRECIATION	2940.
INTEREST	3213.
TAXES	695.
FIRE AND LIGHTNING INSURANCE	154.
TOTAL	7002.

D. WATER COST PER ACRE FOOT

1. FIXED COST = 7002./ 529. AF = 13.24

2. VARIABLE COST = (1.024 * 460 * .01200)/.520 + .007512 * 460
= 14.33

WHERE		
1.024	=	KWH TO LIFT 1 AF OF WATER 1 FOOT AT 100 PERCENT OVERALL EFFICIENCY
460	=	FEET OF LIFT
.01200	=	POWER COST PER KWH INCLUDING SALES TAX
.520	=	OVERALL EFFICIENCY STATED AS A DECIMAL FRACTION
.007512	=	COST OF PLANT REPAIRS, MAINTENANCE, LUBRICATION AND ATTENDANCE PER FOOT OF LIFT

3. TOTAL COST = 27.57

E. KWH OF ELECTRICITY USED TO PUMP 1 AF = 905.85 529 AF = 479193.

Well operation and maintenance charge of $3.46/acre-foot.

Total Well cost = $20.62/acre-foot.

Having derived this unit charge rate and knowing the quantities of water used on each crop (Table 5), water costs may be assigned to each crop. For example, the water used on alfalfa costs solar farm $13,795 (669 acre-foot x $20.62/acre-foot = $13,795). More importantly, we can now estimate the electric power bill paid by solar farm for irrigation pumping, which was a key objective of this chapter; this power bill is 4,449 acre-feet x $10.87 = $48.360. The assumptions regarding pumping efficiency, pumping lift, and electricity price that lie behind this cost are noted on the computer printout.

Materials and Machinery Costs. The next step in budgeting for solar farm is to determine the machinery complement and materials needed to produce the solar farm crops and their costs. This process is rather tedious and is best handled with the assistance of a computer. The information needed to perform these computations, i.e., the basic technical coefficients and price information, are maintained in the Arizona Farm Management Office MIS (for the specific coefficients used in this study see Hathorn et al., 1976 and Hathorn and Wright, 1976). The resulting schedules of materials and machinery for solar farm are provided in the Appendix to this thesis and the associated costs of these materials and machinery are summarized in Table 14, which presents the financial results for solar farm.

Returns

The solar farm described here earns a net return of $37,955 or $37.95 per cropped acre after management fees and taxes and $75.73 per cropped acre before these whole-farm costs are netted out. There is insufficient information to compute a rate-of-return on investment. Alfalfa returns $156/cropped acre, wheat $82/cropped acre and cotton $55/cropped acre. Irrigation related costs, which include not only the cost of the water but also that of the labor in setting up for each irrigation run are proportionately higher for alfalfa than cotton or wheat; that is, the ratio of irrigation costs to all assignable costs is higher for alfalfa (.39) than for either wheat (.27) or cotton (.22). This ratio could be used as an index of the sensitivity of each crop to rising water prices. Irrigation-related costs, however, do not dominate the farm balance sheet. They are an important decision variable for the farm, but not the only decision variable. This point is important to remember when predicting farm adjustments to rising well level water prices, which are, themselves, only a subset of irrigation costs.

The high level of returns on alfalfa may be caused by the assumption that on solar farm the alfalfa crop is watered sufficiently to obtain maximum physical yield. This assumption results from using the Farm Management MIS budgets. According to the Arizona Farm Management Office, Arizona farmers quite often stress alfalfa by cutting off water to it during those summer months when it is competing with cotton for water. The effect of this practice is reflected in the fact that the solar farm's yield on alfalfa per year is 7 tons/acre (Hathorn et al., 1976) while in 1975 the Pinal County average yield was 6 tons/acre (Arizona

Crop and Livestock Reporting Service, 1976). At 6 tons/acre the alfalfa return per acre would drop from $156 to $77, which is in line with the returns on wheat and cotton. See Table 14 for solar farm summaries.

Table 14. Solar Farm Costs and Returns Summary.

	Cubed Alfalfa (107 acres)[a]	Cotton[b]	Wheat (416 acres)	Totals
Gross Revenue	59,920.00	286,678.90	120,744.00	467,342.09
Nonwater Variable Cost	24,648.33	161,775.23	43,628.50	230,052.06
Returns After Nonwater Variable Cost	35,272.00	124,903.90	77,115.50	237,290.50
Water Variable Cost	12,530.92	41,807.61	22,921.86	77,260.39
Returns After Water Variable Cost	22,741.08	83,096.29	54,193.64	160,030.11
Machinery Fixed Cost	1,633.13[c]	43,358.06	11,573.47	56,564.66
Well Fixed Cost	4,332.97	15,114.87	8,286.45	27,734.29
Farms Returns After Assignable Fixed Costs	16,774.98	24,623.36	34,333.72	75,732.06
	($156/acre)	($55/acre)	($82/acre)	$75.73/acre)
			5% Management Fee	23,367.15
			General Farm Maintenance	12,000.00
			Returns Before Taxes	40,364.91
			Property Taxes (Realty)	2,410.00
			Net Farm Return	37,954.91
			Farm Return Per Acre	37.95

a. Loaded with one-third of alfalfa stand establishment costs.
b. Consists of 441 acres of upland cotton and 36 acres of Pima cotton.
c. Low fixed cost because of use of custom harvesting.

CHAPTER III

DETERMINATION OF ECONOMICALLY JUSTIFIABLE INITIAL COST OF SOLAR SYSTEM

In this chapter, the total initial cost of a solar-thermal generation plant economically justified by changes in solar farm annual operating costs will be determined. It will be assumed throughout that all energy for pumping groundwater will be supplied by the solar plant. If for whatever reason this assumption does not hold, the justified initial cost of the solar plant must be reduced in proportion to the share of total groundwater pumping energy that is supplied by the solar equipment.

Computational Approach

Basically, the computational procedure followed in this chapter will be to isolate the cost of electrical energy for irrigation pumping out of total farm cost and to convert this constant annual cost stream to its present value equivalent. This present value figure represents for solar farm the maximum justifiable investment in solar equipment that frees solar farm from the need to purchase electricity. Note that "justified investment" is not the same as "justified initial cost"; this distinction will become clear shortly. At the present stage in the development of solar power, it is felt to be purposeless to consider the effect of such changeable policy items as accelerated depreciation rules and special investment credits on the solar investment decision. To some extent the effect of policy variables are represented by including different discount rates. To give the following results as broad an applicability as possible, investment levels will be computed over a wide range of pumping lifts and pumping efficiencies.

A basic solar thermal plant will be described in Chapter IV. At this stage of the analysis, however, some idea of how a solar plant operates must be introduced. A solar thermal electric plant has two major sections. The first section, termed the collector, gathers the diffuse incoming radiant energy of sunlight and concentrates it to the high levels needed for generating electricity efficiently. At the present time there are several ways that seem possible for doing this energy collection job; the one we have assumed for this study is called a central-tower collector. In the central tower collector, special mirrors focus solar energy onto a central tower through which a fluid is passed. This fluid collects the focused solar energy in the form of heat. Collector technology for thermal-electric plants is mostly unproven. We will assume an operational life of 15 years for this section of the solar-thermal plant.

The second section of the solar-thermal plant generates the electricity from the heated fluid. The technology for doing this job is well understood; the main questions revolve around the method for generating the electricity most efficiently at the relatively low working fluid enthalpies expected. Electrical generation equipment is commonly assumed to have an operational life of 30 years.

Because the two sections of the solar plant have distinctly different operational lives, some scheme must be derived for dividing the justified investment between the collector section and the generating section. The planning horizon of the solar plant will be taken at 30 years. During this time, the solar farm must purchase one generating section and two collector sections; one collector is purchased at year zero and one at year 15. The purchases must be made while staying within the justified investment bound. The purchase cost of the generating section and the first collector section will, then, be the justified initial cost for the solar-thermal generating plant. This basic design parameter will be presented for several different future situations as characterized by pumping lift and pumping efficiencies and by prevailing interest rates.

Justifiable Investment in Solar System

The dollar cost of the electrical energy (C_e) needed to pump one acre-foot of water is given by:

$$C_e = 1.024 \text{ (lift, foot) } (P_e)/\text{OPE}$$

where lift is the pumping lift of the well, P_e is the electricity rate paid in dollars per kwh, and OPE is the overall pumping efficiency. Each of these three cost-controlling variables for solar farm will be examined in turn.

Pumping Lifts

Pumping lifts in Pinal County are highly variable but on the whole fairly large. Hathorn's pump water budgets (Hathorn, 1976) show average lifts from 395 feet in the area of Coolidge to 610 feet in the area of Stanfield. Morin (1976) estimates the typical pumping lift at 325 feet (see Table 2). For the solar farm budget of Chapter II, a typical case value for pumping lift of 460 feet was used.

Note that in choosing the proper solar plant size, the engineer will have to consider in his design the possibility of changes in pumping lifts over the life of the plant. Here, however, pumping lifts will be looked at as holding constant for solar farm over the entire operating life of the solar plant. Grant and Ireson (1970, p. 42) show that a gradient, i.e., arithmetic, series of constant increases, G, over n years can be converted to an equivalent constant annual figure, A, by the expression:

$$A = \frac{G}{i} - \frac{nG}{i}\left[\frac{i}{(1+i)^{n} - 1}\right],$$

where i is the discount rate. For example, say pumping lift is increasing at 8.1 feet/year, which according to the Arizona Water Commission (1975) is the typical annual fall in the water table in Pinal County. For a discount rate of 8.5% and a planning horizon of 30 years, A is given by

$$A = \frac{(8.1)}{.085} - \frac{30\ (8.1)}{.085}\left[\frac{.085}{(1.085)^{30} - 1}\right]$$

$$= 72.3 \text{ feet}$$

Thus, a 460 foot constant lift for 30 years would be economically equivalent to a situation where the lift in the first year was 387.7 feet, rising in 8.1 foot increments to 626.6 feet by the thirtieth year.

Electricity Prices

The price of electrical energy at various locations in Pinal County given in the Hathorn budgets (Hathorn, 1976) is as follows:

Coolidge	12 mills/kwh
Casa Grande	12 mills/kwh
Eloy	11 mills/kwh
Stanfield	26.3 mills/kwh
Maricopa	13.5 mills/kwh

For the solar farm base case a typical energy price of 12 mills/kwh was chosen.

Pinal County electricity prices are unusual in two respects. The first respect in which the prices are unusual is that the electric districts[1] serving Pinal County farmers charge one flat rate no matter how much electricity is consumed. More typically in Arizona a declining block rate pricing schedule is used. Fuel adjustments and taxes are overlain on this schedule. For example, the two largest utilities in the state, Arizona Public Service and Tucson Gas and Electric, both use the declining block rate method. Also, both weight the block prices by the peak potential demand of the well as measured by the size of the electric motor being served.

The second respect in which Pinal County electricity prices are unusual is that relative to other prices for similar service, they are very low. Nationwide the cost of electricity generation is typically 20 to 25 mills/kwh (Conn and Kulcinski, 1976). No other area of Arizona enjoys prices as low as those seen in Pinal County. The highest electricity price for irrigation service at the time of the writing of this thesis is the 40.15 mills/kwh Tucson Gas and Electric charges for its first block. Typical Arizona 1975 electricity prices in other counties work out to flat rate equivalents of from 23.0 to 27.7 mills/kwh (Hathorn, 1976). Pinal County electricity prices are low seemingly because the electric districts were able to obtain long term contracts for large amounts of cheap hydroelectric power. According to Hathorn, these supply contracts will typically remain in force for another decade.

1. Electrical districts are electrical retailing cooperatives run in the interest of local agricultural and other users.

Overall Pumping Efficiency

The overall pumping efficiency parameter measures how well the motor and pump are doing their work. OPE, like pumping lift, shows a wide range of values in the field. To a certain extent, the OPE level is under the control of the farmer through maintenance and replacement. For the solar farm base case the typical OPE was set at .54. This value will probably become lower than typical as energy prices move up; however, the leeway in optimizing pumping efficiency is not great enough to counteract very large electricity price rises or pumping lift increases. The theoretical maximum OPE is about .75 (Nelson and Busch, 1967).

Electricity Cost Computation

Electricity costs for solar farm are computed in Table 15 for the base case and some variational cases. The high OPE of .66 used in the table was picked as the highest OPE level that could be maintained on an irrigation well for a year. Note from the table that the farmer could maintain the same level of electricity costs up to a depth of 560 feet by adjusting the OPE but that beyond this depth the electricity bill will begin to rise. The typical case figure of $46,580 represents about 11% of the total solar farm costs.

It should be noted here that solar plants may have another effect than just merely ending the annual stream of farm electricity purchases. It seems fairly certain that additional annual operation and maintenance charges will result for the solar farm. There is even some likelihood that solar plants will require fulltime attendance. Whatever these additional O&M charges may be, the potential annual cost savings from using

Table 15. Annual Costs of Electricity to Solar Farm.[a]

Overall Pumping Efficiency	Pumping Lift (feet) Very Shallow (200)	Shallow (360)	Typical (460)	Deep (560)
Low (.42)	$26,038	$46,869	$59,889	$72,908
Typical (.54)	$20,252	$36,454	$46,580	$56,707
High (.66)	$16,570	$29,826	$38,111	$46,397

a. 4,450 acre-feet annual pumpage; price of electricity is 12 mills/kwh.

solar power would have to be adjusted downward for them. The same caution also applies to the results shown in the following two tables. For example, if the additional farm O&M from a solar plant is \$16,700 per year, for an efficient well with a 200-foot pumping lift, there are annual disbenefits of \$130 (\$16,570 - \$16,700) to using solar power on the farm (see Table 15). Estimates of how much O&M will cost for solar plants at this point in the development of solar power are purely guesswork, but it will clearly be seen during the development of this chapter how vital it is to the feasibility of using solar power for irrigation pumping that this parameter be kept as low as possible.

Present Worth Computation

The present worth factor for determining the present value of an annual series of payments (P/A) is derived in most beginning engineering economics texts (see, for example, Grant and Ireson, 1970). It is:

$$(P/A) = \frac{(1 + i)^n - 1}{i\,(1 + i)^n}$$

Here i represents an assumed constant interest, or discount, rate and n represents the number of interest periods. The number of interest periods will be taken to be the number of years in the operational life of the solar-thermal plant, 30 years.

The i variable in this equation is the long-term opportunity price of money to the farmer. If society undertakes to encourage solar-energy use for extra economic reasons, the opportunity price of money used to purchase solar equipment seen by the farmer might be quite low, say about 4%. On the other hand, without loan guarantee programs, farmers may have a difficult time arranging the financing needed for the new, unproven solar technology from risk averse investors and might have to pay a risk premium, raising i up to, say, 13%. The solar farm will be assumed to be able to obtain funds for the solar equipment at 8.5%. (The Farm Administration (U. S. Department of Agriculture, 1975) states that interest rates on agricultural loans stood at between 8.5% and 9% on June 30, 1975).

Table 16 shows the justified investment levels for discount rates of i = .04, .085, and .13. The values are computed by multiplying the present worth factor by the annual costs of electricity computed in Table 15. For the typical case (lift = 460 feet, OPE = .54, i = .085) the justified investment is about one-half million dollars over the 30-year project period.

Justifiable Solar System Initial Cost

The justified initial cost for the solar plant is estimated by apportioning the justified investment derived in the previous section between the collector and generating sections of the solar plant. This must be done so that, first, sufficient investment "funds" are retained after the initial purchase to purchase a second collector section at 15 years, and that secondly the ratio between the capital costs of the collector and the generating section is maintained at 3:1. (This estimate or cost proportions is based on discussions with Larson (1976) and Sands (1976). The "justified initial cost" is the delivered and operating costs for a solar plant at year zero. It does not include the cost of the later collector. It should include adjustment for the additional

Table 16. Justified Investment in Solar Equipment for Various Values of Pumping Lift, Pumping Efficiency, and Discount Rates (1976 dollars).

Overall Pumping Efficiency		Pumping Lift Very Shallow (200 feet)	Shallow (360 feet)	Typical (460 feet)	Deep (560 feet)
Low (.42)	i = .040	450,197	810,460	1,035,602	1,260,727
	i = .085	279,826	503,694	643,618	783,531
	i = .130	195,172	351,314	448,907	546,493
Typical (.54)	i = .040	350,198	630,364	805,463	980,579
	i = .085	217,645	391,765	500,588	609,421
	i = .130	151,802	273,246	349,148	425,056
High (.66)	i = .040	286,529	515,752	659,016	802,298
	i = .085	178,075	320,535	409,573	498,621
	i = .130	124,203	223,565	285,567	347,775

operation and maintenance annual cost streams that are introduced on the farm by the solar plant.

Justifiable Cost before O&M Charges

As we have noted earlier, fixed electrical generation equipment typically is expected to have an operational life of around 30 years. On the other hand, the solar collector section of solar-thermal generation plant, which both requires untried technology and which will necessarily be subjected to a somewhat severe physical environment, has been assumed to have an operational life only half that of the generating section. Accurate estimates of operating life prepared in advance of actual experience with the collector equipment are very difficult to make.

To satisfy the electrical demands of farms similar to the solar farm described in Chapter II, farms ranging in size from roughly 200 to 2,000 irrigated acres requires solar-thermal plants of from 1 to 10 MW_t. ("MW_t" means megawatts-thermal and refers to the maximum rate heat is generated within the solar plant; this parameter can be used to characterize the plant capacity as can "kw_e," or kilowatts-electric, which refers to the power output of the plant.) For such plants it is estimated that three-fourths of the initial capital costs will be spent on the shorter-lived collector section.

The basic present value problem is somewhat complicated here by the fact that the collector section of the solar suite only operates for 15 years. If solar farm were to spend all its justified investment from Table 16 immediately, the solar plant would operate for only 15 years. After the 15 years were up, solar farm would be left with an inoperable collector hooked up to a still operable electrical generation system. No further investment could be justified for replacing the solar collector. So, the problem is to determine how much of the total justified investment capital can be invested in a generator and collector, that is in a solar plant, at the start of the project and how much of it should be conserved for purchase of a second solar collector 15 years into the project.

Looked at from a different point of view, solar farm may not use all of the justified investment at the start of the project because if it did it would again be faced with paying for off-the-farm electricity between the fifteenth and thirtieth year of the project. This would violate the assumption under which justified investment was computed. Since it may not "invest" all of the stream of electricity costs in solar equipment initially, it in effect has a stream of savings for the first fifteen years, and it then invests this money (principal and interest) at the fifteenth year in the second collector section.

Let C_c be the justified initial cost for the collector section and C_g be that of the generating section of the solar plant. The total justified initial cost for the solar plant is:

$$C_t = C_c + C_g$$

From the present worth factor and the constant annual solar farm electricity costs over 30 years the upper bound on current solar investment has been computed; call this I_t . I_t is the maximum amount of capital solar farm can justifiably commit to the purchase of a solar system over the 30-year project and still leave its financial position unchanged.

It is assumed that solar farm will pay the same amount at the start of the project for a collector as it pays in the fifteenth year, that is, that the cost of the collector does not change with time. The amount of the justified investment not spent at the start of the project ($I_t - C_t$), that is, the amount conserved for purchase of the second collector, together with its compounded interest, is made to equal the justified cost of the collector section at the fifteenth year, that is:

$$C_c = (I_t - C_t)\ (1 + i)^{15} = (I_t - [C_c + C_g])\ (1 + i)^{15}$$

It was estimated that the ratio between the initial cost of the collector section and of the generating section is 3:1, or $C_g = 1/3\ C_c$; substituting this expression into the above equation results in:

$$C_c = (I_t - [4/3]\ C_c)\ (I + i)^{15},$$

and, solving for C_c:

$$C_c + (4/3)\ C_c\ (1 + i)^{15} = I_t\ (1 + i)^{15}$$

$$C_c = I_t\ (1 + i)^{15}\ /\ (1 + [4/3]\ [1 + i]^{15})$$

Since I_t is known from Table 16, C_c may be computed. With C_c known the values of C_g and C_t quickly follow. The results of this computation are shown in Table 17.

The figures in Table 17 estimate the level of initial cost the solar system designer will have to meet to compete with conventional energy pumping systems for farms operated similarly to solar farm. The most likely "future states" lie along the diagonal running from the upper left to the lower right of the table. As expected, the results show the following: the more efficient the farm wells, the less the justified initial cost level for solar; the higher the interest rate, the less the initial cost; and the greater the pumping lift the greater the

Table 17. Justified Initial Costs for Collector Section, Generator Section, and Total Solar Power Plant for Solar Farm Financial Breakeven in Thousands of 1976 Dollars.[a]

		Pumping Lift					
		Shallow (200 feet)			Moderate (360 feet)		
		Collector Section	Generator Section	Total Solar Power Plant	Collector Section	Generator Section	Total Solar Power Plant
Low	i = .040	211	70	281	429	143	572
OPE	i = .085	170	56	226	306	101	407
(.42)	i = .130	131	43	174	234	78	312
Typical	i = .040	185	62	247	334	111	445
OPE	i = .085	132	44	176	238	79	317
(.54)	i = .130	100	34	134	161	50	212
High	i = .040	151	51	202	273	91	364
OPE	i = .085	109	36	145	195	65	260
(.66)	i = .130	82	27	109	148	50	198
		Typical (460 feet)			Deep (560 feet)		
Low	i = .040	549	182	731	667	223	890
OPE	i = .085	389	130	519	474	158	632
(.42)	i = .130	299	100	399	364	122	486
Typical	i = .040	426	143	568	519	173	692
OPE	i = .085	303	101	404	368	122	490
(.54)	i = .130	234	78	312	283	95	378
High	i = .040	349	116	465	424	142	566
OPE	i = .085	247	82	329	300	100	400
(.66)	i = .130	190	63	253	232	77	309

a. Costs exclude downward adjustment for additional O&M added to farm budget because of presence of solar plant.

initial cost. For the typical OPE and lift at the typical interest rate, a $404,000 investment in the solar suite is justified even at the low electricity prices currently existing in Pinal County. (Note the figures in the table can be used for rough estimates of the per acre amount of justified initial cost; that is, in the typical case the result might be read as $404 of initial solar plant cost per acre of irrigated crop on solar-farm type farms.) Doubling the price of electricity, which would about bring it in line with the going rate elsewhere in the state, will double the justified initial cost of the solar plant. Recall, however, in return for this investment in solar equipment it was assumed at the beginning of this chapter that all conventional energy requirements are obviated. As was mentioned in Chapter II in discussing the duty factor, there are technical reasons why this may not be a practicable approach. A discussion of solar system alternative suites will be taken up in the latter part of the next chapter.

Justifiable Cost after O&M Charges

It should also be noted again that in computing Table 17, the effect of the additional solar farm O&M charges caused by the solar plant have not been included. As an example of the possible magnitude of the effect of additional O&M on the results, if, for the typical case, $16,700 is in fact required per year to maintain and operate the solar plant, the annual effect of the solar system on the solar farm budget is a savings of $29,880 rather than $46,580, 36% less. As a result, the justified level of solar system cost would likewise be reduced by 36% of its Table 17 level, that is, from $404,000 to $259,000. Under the same assumed level of O&M, $16,700, the largest justified initial cost (for OPE = .42, lift = 560 feet, i = .04) falls from $890,000 to $686,000, while at the lowest level of justified initial cost (OPE = .66, lift = 200 feet, i = .13) the investment is not worthwhile for any solar plant cost. Some other drops in initial cost with $16,700 of annual O&M are from $400,000 to $256,000 at OPE = .66, lift = 560 feet, i = .085; from $317,000 to $172,000 at OPE = .54, lift = 360 feet, i = .085; and from $226,000 to $81,000 at OPE = .42, lift = 200 feet, i = .085.

These examples of the effect of O&M charges on the justified initial cost of a solar plant should be sufficient to show the dramatic sensitivity of initial justified costs of the solar plant to the assumptions regarding O&M levels. The $16,700 estimate is based on one man-year of skilled labor plus about $4,000 for tools and materials. Further development of these compensated initial cost estimates is unwarranted because of the perforce low quality of the estimate of O&M charges.

Other Factors Affecting Justifiable Cost

By comparing Tables 16 and 17, some idea of the effect of the length of the operating life on the justified initial cost of the collector section can be gained. Again for the typical case, for collector operating life of 30 years rather than 15 years, the initial collector cost rises from $303,000 to $375,000. Comparing the figures from Tables 16 and 17 should give the solar designer some idea of what an extra 15 years of life is worth and of how much can be spent for the extra fabrication care and the more endurable materials. Along the same lines, if the proportion of total initial costs going into the shorter-lived solar collector could be reduced from 3/4 to 1/2 in the typical case, the total justified initial solar system cost would rise from \$404,000 to \$436,000. Using the same approach as above, it can be shown that if the collector operating life happens to be 10 years rather than 15 years, initial cost as a percentage of justified initial cost falls from 80% to about 70% of justified total investment.

This concludes the derivation of the justified initial cost of a solar-thermal electrical generation plant for solar farm. Awareness of the method used here is as important as the results. Consideration of such questions as how solar farm could carry the extra several hundred thousand dollars of financing needed is important but beyond the scope of this thesis. In Chapter IV, estimates of the actual initial cost of a solar plant will be derived and the entire question of feasibility will be recast into a framework of electrical power prices.

CHAPTER IV

DESCRIPTION AND ASSESSMENT OF BASIC SOLAR SYSTEM AND ALTERNATIVES

The basic solar system envisioned for use on Pinal County farms for irrigation pumping is built around a central, solar-electric power station. This station supplies electricity through existing power lines to all remote well sites. Such an arrangement is attractive since it allows the farmer to locate the solar plant in an area of the farm that is not cropped. The solar plant should have no effect on existing wells. There should be no difference in irrigation operations between operating with electricity from a central solar plant or with electricity supplied from off the farm except in the limited hours of availability of solar electricity. Transforming solar energy to electricity also makes it possible to perform farm jobs other than irrigation with solar electric power and to sell or trade excess electric capacity to electrical utilities. There is generally a high-level of flexibility possible in the central plant arrangement. Considerations regarding alternative system arrangements will be discussed toward the end of this chapter.

Basic Solar System Plant

Figure 3 shows the arrangement of major components in a basic solar-thermal electrical generating plant such as might be built on a heavily irrigated Arizona farm.

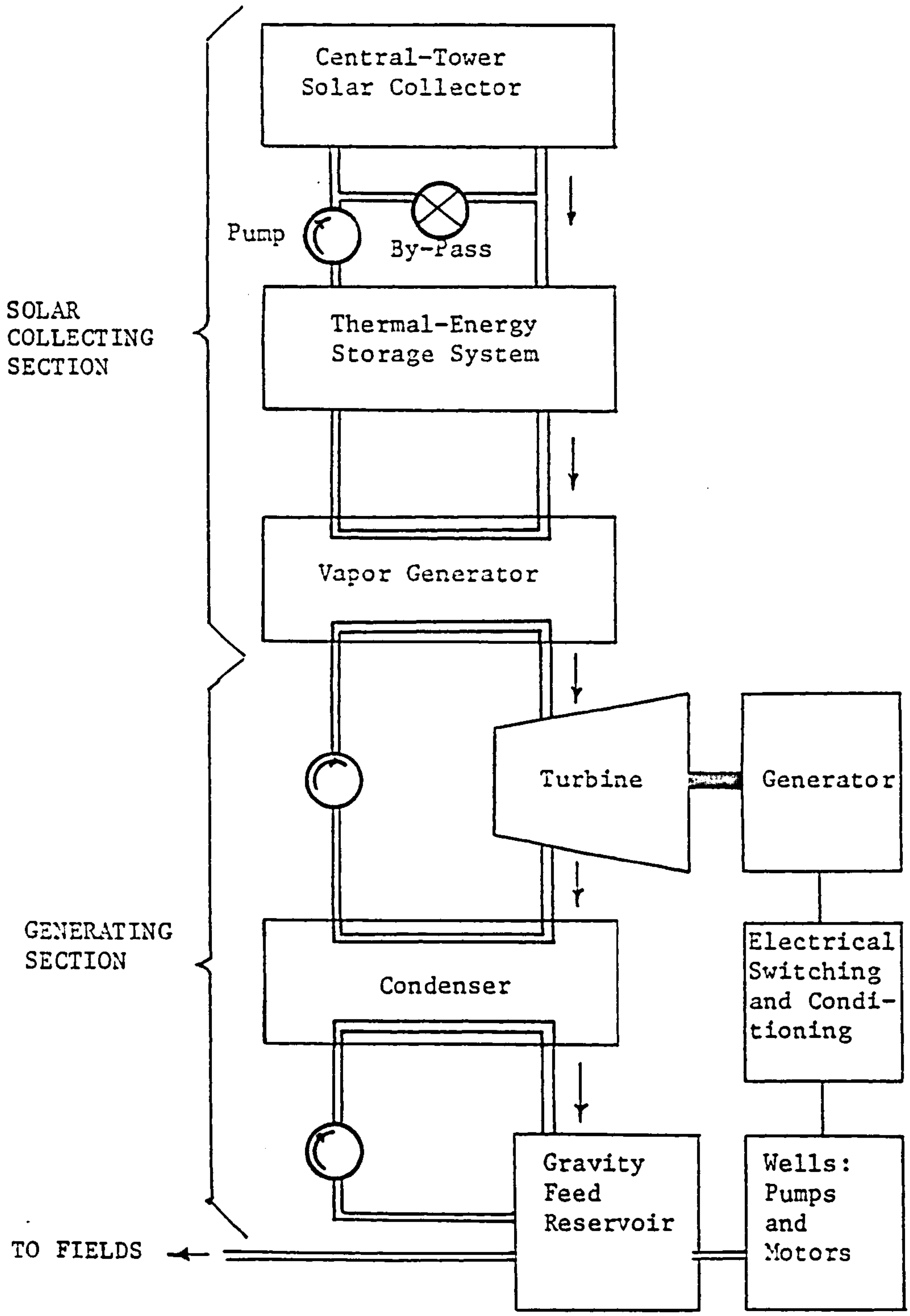

Figure 3. Basic Arrangement of Components for Solar System.

Physical Description

The solar-thermal electricity plant consists of two main sections: a solar-collector section and a generator section. The solar collecting section comprises the collector itself, an auxiliary energy storage or heat generation component, and a means of transferring this heat to the generating section. The generating section comprises a turbine, the generator itself, associated switching and supporting gear, and a condenser.

The solar collector expected to be used for the thermal-electric solar plant is of the central-tower type. In a central-tower collector the radiant energy from the sun is focused by a large field of specially shaped mirrors onto an elevated collector pipe located centrally in the mirror field. A high heat capacity fluid passing through this pipe is heated to a high temperature and pressure by the solar energy.

After leaving the collector area, the fluid is conducted through a short-term thermal storage system. Here the heat gathered from the energy of the incoming sunlight can be stored possibly by heating rocks. The heat-storage system functions as an auxiliary energy source during short periods of a few hours or so when sunlight is reduced. It also serves to carry irrigation operations on into the evening hours. A small, conventionally fueled boiler might also be introduced into the system here for the same purposes.

Following its passage through the heat storage component, the collector fluid enters a vapor generator, or heat exchanger. In the vapor generator the working fluid of the collector gives up its heat energy to a second fluid that is used to drive a turbine. The first fluid is then pumped back to the central tower. Two different fluids are used in the solar plant because of the two different types of jobs that must be done by them. The first fluid gathers and transports heat, and the second, after its conversion to a vapor, drives the turbine.

The turbine converts the heat energy carried in the second fluid vapor into mechanical energy in the rotating shaft of the turbine. In the basic solar plant, this rotating shaft is coupled to an electrical generator; alternatively, the shaft could be coupled directly to the well with no intermediate conversion of the energy to electricity. After leaving the generator and being transformed to the proper voltages and wave form for the electric motors, the electricity is switched into the existing power grid and transmitted to the individual wells. One or several of the wells might supply water to a reservoir. The water supply is used for condensing the spent fluid leaving the vapor turbine. One of the options to the basic design being described here is to store the water needed by the irrigation system temporarily in a gravity-feed reservoir, rather than pumping it directly to the fields. This may be necessary in some situations to match sunlight availability and crop irrigation needs. This option and others will be considered toward the end of this chapter.

The estimated efficiency with which the energy conversions (from radiant-solar to heat to heat to mechanical to electrical) will be made is about .12. From the collector tower to the electricity output the plant efficiency is .16 (Sands, 1976). For an average coal-fired thermal-electric plant, the comparable efficiency level is about .33.

Estimate of Basic Solar Plant Cost

Solar-thermal systems for generating electricity on the scale needed by large Arizona farms are not, as of 1976, advanced far past the conceptual, block diagram stage of development described previously. Even less advanced are solar electric systems built around solar cells, i.e., devices for converting solar energy directly to electrical energy. Despite the existence of ongoing design development on solar collectors being carried out at several institutions in the United States, including the University of Houston, specific cost estimates for the collector and for entire solar-thermal electric generation systems are quite preliminary. In preparing cost estimates for the solar farm installation, the basic source of cost information used was data gathered by Strickland et al. (1976). The preparation of specific solar-plant cost estimates for solar farm was supervised by Sands (1976).

Before a cost estimate for the solar farm can be made, the size of the solar plant needed must be estimated. For this basic estimate the extra costs needed to match the solar plant availability with respect to sunlight hours to the solar farm crop irrigation schedule will be ignored for the moment. This problem will be considered later. From the results of Chapter II for the typical case (460 foot lift, OPE of .54) the representative solar farm consumes 3,881,700 kwh (or 443 kw_e peak capacity) in raising 4,450 acre-feet of water. For the busiest month, April, the 609 acre-feet needed requires 531,230 kwh of electricity (or 738 kw_e peak), and for the highest semimonthly period, late May, 335 acre-feet are pumped, requiring 292,220 kwh (761 kw_e peak capacity). The maximum possible electric demand by the four 1,200 gpm well system is

800 kw_e. Thus, for a solar-thermal to electrical transformation efficiency of .16, the appropriate size of the solar plant for the representative solar farm would be (800 kw/.16) 5.0 MW_t.

The estimates of initial costs for a 5-MW_t solar generating plant to supply all four wells of solar farm are (Sands, 1976):

central-tower collector	$ 750,000
800-kw_e turbine/generator	114,400
vapor generator	20,000
condenser	39,500
thermal-storage capability	90,000
plumbing	45,000
switching and controls	20,000
equipment subtotal	$1,078,900
construction costs (administration)	50,000
buildings and improvements	50,000
TOTAL INITIAL COSTS	$1,178,900

The thermal storage device assumed here possesses sufficient capacity to drive the turbine-generator for three hours on its own after being fully charged; however, the thermal storage component may be the least well understood item in the entire solar electric plant. An auxiliary, conventionally fueled boiler and a large water reservoir are not included in this first basic estimate of generalized solar-thermal plant costs. It is also assumed that this estimate is for an operational plant and not for a prototype one. The cost of a prototype plant would probably be an order of magnitude greater than the cost total shown above.

The $1.2 million estimate above exceeds all the earlier estimates of justified initial cost for a solar-thermal electrical generation system for solar farm even though the extra costs needed to match the solar installation to solar farm's irrigation schedules have not been added in as yet. Only the justified cost figures for an OPE of .54 and a pumping lift of 460 feet in Table 17 should be compared with the $1.2 million figure above since different physical situations will require different sizes of solar plant. For the typical solar farm case the estimated cost of the solar plant is three times its justified initial cost even when both are viewed under the most idealized and favorable of circumstances. If the price of financing the solar plant is subsidized in some fashion to lower the effective discount rate for solar farm to .04, the estimated cost of the solar plant is still twice that justified. The highest justified cost, viz., for a farm with a low OPE and a large lift and with access to subsidized funds is $890,000. A solar plant large enough for such a situation would cost roughly $1.9 million (scaling cost linearly with increasing energy output); in this case, again, the justified initial cost is still only half the estimated plant cost.

Solar Energy "Price"

Since the justified investment rises proportionally with energy price, the above results can also be stated in terms of price; the solar-thermal generation system would be feasible in its basic arrangement if the present price of electricity in Pinal County were to rise roughly three times above its present 12 mills/kwh level. A doubling of Pinal electricity prices seems probable when current long-term contracts for electricity from hydropower projects held by the various electric districts expire. An eventual further 50% relative price rise beyond that level does not seem beyond reason given the increasing scarcity of fossil fuels. Because of the length of electric district contracts, Pinal County farmers will probably not be interested in considering solar power for pumping groundwater before about 1990 except possibly in a few individual situations.

These results might be more informative to some if cast directly in terms of price rather than investment levels. The farmer will carry a cost in his books representing the capital recovery charge for the investment he has in the solar equipment. If he amortizes the collector over 15 years and the other solar system components over 30 years, both at a discount rate of 8.5%, then, the annual sinking fund level will be $90,315 for the collector and $49,909 for the other system components for a total of $130,224. Expressed in terms of dollars per kilowatt-hour based on the annual kilowatt-hours used on solar farm (3,881,700 kwh), the sinking fund level becomes a surrogate "price" for solar generated electricity. For solar farm this surrogate price is 33.5 mills/kwh, <u>2.8 times the present 12 mills/kwh rate</u>.

The presence of the solar equipment adds to the operation and maintenance charges of the solar farm budget. The major share of these charges is due to the fact that the solar equipment is expected to require constant attendance when in operation (Sands, 1976). To cover additional O&M charges of $16,700, the basic 33.5 mills/kwh price must be raised by 4.2 mills/kwh to 37.7 mills/kwh, <u>3.1 times the present Pinal County electricity rate</u>.

Economists willing to predict future electricity prices are not very common. It is a difficult and uncertain business. Joskow and Baughman (1976) have made such estimates based on large-scale modeling of the U. S. economy in connection with their study of the future of the U. S. nuclear energy industry. They develop price results for nine future energy scenario cases. The most interesting of these cases are: Case 1, a base case in which all prices remain at current levels but in which natural gas is unavailable to all but the most critical uses; Case 2, where high air pollution standards are placed on coal and oil-fired generating plants; Case 4, in which utility plant siting regulations and procedures are streamlined; Case 7, in which it is assumed that the cost of fuel for fission plants becomes quite high; and Case 8, in which the OPEC cartel breaks up. Table 18 shows the Joskow and Baughman results. Unfortunately, the Joskow and Baughman results are in nominal-dollar terms while the results of this study are in constant 1976 dollars. The numbers in parenthesis in Table 18 are Jaskow and Baughman's results deflated for a long-term 4% inflation rate in the economy.

From Table 18, and if the assumption of a long-term inflation rate of 4% over the next 20 years is correct, the greatest "natural" rate of increase in the price of energy is 1.2% (Case 7) and the least .8% (Cases 1 and 2). If it could be presumed that the 1.2% rate of growth in energy prices would continue past 1995, it would require 38 years, till about 2015, for solar to be equal to the price of electricity from conventional sources. On the other hand, the base case scenario indicates solar feasibility might be as far off as 100 years.

Table 18. Electricity Price Projections.[a]

Year	Case 1	Case 2	Case 4	Case 7	Case 8
1980	30.4 (25.0)	32.4 (26.6)	30.4 (25.0)	30.9 (25.4)	28.5 (23.4)
1985	37.6 (25.4)	38.5 (26.0)	37.0 (25.0)	38.5 (26.0)	36.7 (24.8)
1990	47.0 (26.1)	47.4 (26.3)	46.2 (25.6)	50.1 (27.8)	46.1 (25.6)
1995	60.9 (27.8)	60.9 (27.8)	64.8 (29.6)	65.9 (30.1)	65.1 (29.7)

a. Prices in mills/kwh.

Source: Joskow and Baughman (1976, p. 20).

Conn and Kulcinski (1976) have recently estimated the price of electricity generation with various technologies in Science. They estimated the price of solar electricity at roughly three times the 37.7 mills/kwh estimate here (expected value of 108.3 mills/kwh with a range of from 70 to 185 mills/kwh). The prices they report for various existing different technologies were from 20 to 27 mills/kwh for current coal-fired steam and light-water reactors and from 20 to 30.5 mills/kwh for oil-fired gas turbine generators. For near future technologies, geothermal power is estimated at from 25.8 to 52 mills/kwh and fuel cells from 55.8 to 74.2 mills/kwh. For post-1990 technologies they estimate the fast-breeder reactor at from 30.8 to 49.2 mills/kwh, Tokamak-type fusion power at from 40 to 62.5 mills/kwh, and electricity from magnetohydrodynamic (MHD) technology at from 49.2 to 67.7 mills/kwh.

From the Conn and Kulcinski (1976) estimates it appears that solar-thermal electricity as estimated herein would be competitive with those future possible sources of power now seen as contributing to the national energy picture after 1990. Solar is roughly 50% more expensive than existing technologies for electrical generation. Present technologies for generating electricity, however, rely on fuels (fossil fuels and uranium) that are in increasingly short supply. The 37.7 mills/kwh price put on solar power here is probably at the lower end of the possible price range for solar-thermal power; still, solar power should be competitive in an age of fossil fuel depletion with the other technical alternatives in view.

Crude comparisons of the economic worth of different technologies for generating electricity can also be made on the basis of dollars invested per kilowatt of capacity built. For the 5-MW_t plant considered earlier, this figure of merit is \$1,475/kw_e (1976 dollars). Other estimates of capital-to-capacity ratios are presented in a recent publication by the Western Interstate Nuclear Board (1976). These estimates, all for solar plants, are \$1,490/kw_e by MITRE Corporation (1970 dollars), \$930/kw_e by The University of Houston/McDonnell-Douglas Corporation, and, on the low end, \$735/kw_e by the Federal Energy Administration "Project Independence" staff. These estimates are generally for larger plants than the one considered here. In contrast the investment ratio stands at \$350/kw_e for fossil fuel plants with modern technology, \$480/kw_e for light-water fission reactors, and \$555/kw_e for the breeder reaction. (These latter values are from Manne, 1973 inflated to 1976 dollars).

Further Considerations

In the remaining portion of this chapter some alternatives to the basic solar plant will be given and the effect of varying some of the key operating parameters of solar farm on the study results will be assessed. Specifically, the effects of increasing pumping lift on costs, the assumptions regarding overall pumping efficiency, and the effects of rising energy prices on farm returns will be described. The first order of business, however, is to explore the options open for matching the operating schedule of the basic general solar plants to the specific irrigation schedule of a solar farm.

Options for Matching Basic Solar System to Farm Irrigation Schedule

Considering the specific solar farm irrigation schedule developed earlier and using only the basic solar plant configuration just described, insufficient sunlight operating time is available to assure satisfaction of semimonthly farm water pumping needs. As was mentioned in Chapter II, some option must be built into the basic solar plant irrigation system to increase its capability to operate during the periods of most intense irrigation. These options are discussed in the following section. The parameter values used in this section of the study are not meant to be interpreted as anything other than broadly indicative of hopefully reasonable estimates. This section, therefore, is meant to indicate what tradeoffs among options must be considered, but the tradeoffs cannot actually be made until engineering definition of the solar-thermal components and environment is further advanced. The main reason consideration of solar plant operation availability has been postponed to this section is the desire to avoid debilitating the earlier basic cost estimates by adding into them the less certain ones presented here.

By extrapolating some of the data from Chapter II, the duty factor needed to satisfy irrigation needs and the best available plant operational duty factor because of the length of day can be derived (Table 19). In deriving the solar plant duty factor it was assumed that the short-term energy storage component already included in the basic system is used only to counterbalance the hours of cloudiness experienced during the year and that the system was up to design-level power output for all but 5% of the daylight hours on either end of the

Table 19. Matching of Irrigation Needs with Sunlight Available.

Period	Duty Factor Needed	Duty Factor Available
January		
Early	.33	.37
Late	.41	.38
February		
Early	.35	.39
Late	.37	.41
March		
Early	.56	.43
Late	.77	.45
April		
Early	.96	.48
Late	.96	.50
May		
Early	.80	.52
Late	.99	.53
June		
Early	.92	.54
Late	.92	.54
July		
Early	.92	.54
Late	.86	.53
August		
Early	.92	.52
Late	.70	.50
September		
Early	.89	.48
Late	.13	.45
October		
Early	.20	.43
Late	.02	.41
November		
Early	.16	.39
Late	--	.38
December		
Early	.02	.37
Late	.41	.37

day, i.e., for 90% of the sunlight hours. The average duty factor maximum of the basic solar plant is .455. Over a year, then, the basic solar plant will because of the sunlight constraint be able to deliver only enough power to pump 3,520 acre-feet (365 days x 4 pumps x 5.3 [acre-feet/pump/day] x .455). Thus, though the wells are sufficiently large to supply the 4,450 acre-foot requirement of solar farm, because of the solar limit on operating time, the entire system under basic solar power falls short of need by 930 acre-feet.

The unmet water need can be countered with four basic options: the first is to add additional well capacity to the system; the second is to add energy storage capacity beyond the minimum level in the basic system; the third is to purchase the additional energy needed to operate at night from off the farm; and the fourth is to add a reservoir to the farm that would store water from slack pumping periods late in the year to supply it to crops the following spring and summer.

A reservoir could not be used to meet the solar farm irrigation need on its own; it would have to be used together with one of the first three options. This follows since the slack pumping time in the basic system, when the reservoir would be filled, is only sufficient to pump 650 acre-feet. Selecting from among the four options above, then, would be a three-step process of first finding which of the four options is cheapest for supplying the first 650 acre-feet needed, then which of the three remaining options is best for satisfying the last 280 acre-feet needed, and finally, comparing the results from steps one and two to the possibility of using one of the first three options for supplying all 930 acre-feet. The last step is only necessary where marginal investment costs in additional well capacity, added storage energy capacity, or obtaining supplemental energy from off the farm decrease with size.

Costs that would have to be considered for the reservoir system are the cost of excavation, the cost of anti-seepage and anti-evaporation measures, the cost of extra distribution system needed, and the present value of the extra pumping needed. Using cost figures supplied by Sands (1976), the cost of the reservoir alone for solar farm is estimated to be $320,000. This additional cost would raise the total solar system costs up to the neighborhood of $1.5 million. Sand's cost figures also show that, if the reservoir option is selected, the extra expense to control seepage and evaporation is worthwhile.

For the added well capacity option not only would the cost of the wells have to be considered, but also the cost of additional solar plant capacity to power the wells. These costs would add about $390,000 to the basic system estimate, raising it to around $1.6 million. Also, most Arizona farms face legal restraints on the well capacity they can use, limiting them to historical usage levels. These institutional hurdles would have to be cleared.

The thermal-storage option also requires additional collector capacity to supply the extra heat needed; further, the cost of the additional storage capacity is likely to increase faster than the proportional increase in heat storage capacity. Strickland et al. (1976) has analyzed the options being considered here for a solar plant of from 0.5 to 1.25 MW_t size (versus the 5+ MW_t plant used for solar farm). His conclusion is that the best choice is, generally, to select greater thermal-storage capacity. He prices 5.33 MWh_t of storage capacity at $32,000. If this estimate is scaled up for a system to meet the solar farm needs (about 60 MWh_t of storage capacity) about $2 million would be required for investment in the storage component of the system alone. Thus, this option does not seem acceptable.

Additional energy can be brought on to the farm by either purchasing fuel for a boiler that is built into the solar plant or by purchasing electricity directly from a utility for supply to the well motors. Seemingly the latter option would be cheaper than the former since one would expect that the electric utility can generate electricity cheaper than the farm plant using conventional fuels. It seems quite likely that the solar farm and the local utility would be able to arrive at some working agreement beneficial to both parties. Under such an agreement, the farm solar plant would function as a substation during times when the utility faced peak demands in return for the utility's supplying electricity to the farm during peak irrigation times.

There is not enough specific information to decide which of the options discussed above would be the actual one selected. The indication is, however, that the final solar plant irrigation system for the solar farm situation would cost a minimum of $1.6 million. Cast in terms of solar electricity "price" this would represent a minimum price of 50 mills/kwh.

Direct Steam-driven Well Power Systems

There are several ways of designing a solar plant to accomplish the well pumping job other than that shown here though the one shown here is the most probably basic system (Strickland et al., 1976). For instance, it is possible to arrange the solar equipment so that the work of pumping is done directly by a turbine mechanically coupled to the pump shaft. Each well would then have its own individual solar collector system. The existing electric motors on the wells could be sold and replaced by the appropriate mechanical transmission system for connecting the turbine shaft to the well shaft.

Compared to an electrical system, this alternative seems to suffer mostly from lack of system flexibility. Operating and maintaining several separate solar systems would likely be more expensive than it would be for one central system. Because of the lack of data, technical and economic, costs for a direct steam well power system for use on solar farm cannot be estimated. The break-even levels for the representative farm will be about those shown in Chapter III since the salvage value of the existing electric motors is not very great. For the typical solar farm case, then, around $100,000 initial investment would be justified per well.

Water Conservation Alternatives

The first reaction of farmers to higher prices of energy is likely to be to try every means possible to conserve water. The net effect of water conservation changes will be to make solar plant investment look less attractive than it would compared with relatively wasteful use of water. Among the most common means for avoiding water waste are improving the distribution used for delivering water from the wells to the field, better preparation of the field, and the use of irrigation systems that can satisfy plant consumption needs with less water. This study has assumed throughout, in fact, that solar farm has moved quite far in avoiding water losses in the irrigation system. The plant consumptive need of the solar farm crop mix is about 3,100 acre-feet (Arizona Agriculture Experiment Station, 1968); thus, the solar farm irrigation system is operating at an overall water application efficiency of 69%. This is closer to the water application efficiency expected for sprinkler irrigation systems than the historic level encountered with furrow irrigation systems, which encounter closer to 55% efficiency. At a 55% irrigation efficiency the amount of water that must be withdrawn from solar farm wells rises from 4,450 to 5,580 acre-feet, a 1,130 acre-feet increase. Justifiable solar plant initial costs would rise about 25% because of the inefficiency induced pumping.

Effect of Increasing Pumping Lifts on Costs

Most of the attention in this thesis has been directed at rising energy prices as the reason for making the changeover from conventional to solar electricity. Another possible reason might be increasingly large pumping lifts. Greater lifts increase the energy demanded by the wells and thus the electric bill to the farm, and the higher the electric bill the more capital investment the farmer can justifiably put in a solar system.

The above reasoning, however, depends on the cost of providing additional solar power rising less quickly than does the quantity of electricity needed to operate at increasing pumping lifts, that is, on the existence of economies of scale in the solar plant. Scale economies are quite common in the electric utility industry for smaller utilities, but, as it turns out, they seem to represent a rather weak effect in solar technology applications (Sands, 1976).

The weakness of scale economy effects has two major implications for the feasibility of on-farm generation of solar electricity. The first is that solar feasibility is almost indifferent to pumping depth. Greater pumping lifts will continue to penalize farm operations whether solar or conventional energy is employed. The second is that the weakness of scale economies adds greater credence to the concept of generating electricity on the farm. If there were scale economies in solar electricity generation, it would be more reasonable to expect that solar electricity would be generated at a central electric-utility plant capable of realizing these economies as is now the case for conventional energy systems.

For the representative farm and basic solar system, each additional 100 feet of lift requires 1.07 MW additional thermal capacity. Basic solar plants of 4- and 6-MW_t capacity were costed out (Sands, 1976). These plants should be sufficient to satisfy the representative farm power needs at 370 and 550 feet, respectively at an OPE of .54. The 4-MW_t plant (640 kw_e) had a figure of merit of \$1,484/kw_e; the 6-MW_t plant (960 kw_e) had a similar figure of \$1,463/kw_e. The comparable figure for the base case was \$1,475/kw_e.

The solar plant fails to show important economies of scale because the collector, which constitutes well over 50% of the costs of the plant, is assumed to increase in cost proportionally with the amount of energy it must supply. This is so because the amount of energy supplied by the collector is a direct function of collecting area, and most of the costs of the collector are in its sunlight gathering section (mirrors). As further evidence of the weakness of the scale economies effect, going from 4- to 5- to 6-MW_t sized plants results in an average savings of .27 mills per kwh. (This figure was derived using the same computational procedure as for the previous solar energy "price" analysis.) It is assumed that this one-quarter mill scale economy holds constant as the size of the plant increases, even though the collector cost will become increasingly predominant as the size of plant increases and, hence, scale economies will vanish. For this constant scale economy, financial breakeven based on increasing pumping lift does not occur until irrigation wells have reached 4,800 foot lifts.

Effect of Overall Pumping Efficiency

The overall pumping efficiency (OPE) of the well is equal to the efficiency of the electric motor times the efficiency of the pump. It can be computed with the equation:

$$OPE = (\text{discharge, gpm}) \cdot (\text{lift, feet})/kw_d \cdot 5306.4$$

where kw_d is kilowatts input demanded. OPE's found in Arizona vary from under .30 to over .70 (Nelson and Busch, 1967). To some extent OPE's are beyond the control of the farmer since they depend on the design characteristics of the electric motor and the geologic formation from which the well draws water. To a surprising extent, however, OPE can be controlled by an active maintenance program. Under ideal conditions OPE can approach .75 (Nelson and Busch, 1967).

Hathorn (1976) puts great emphasis on the importance of monitoring OPE on the farm and of taking remedial action, i.e., replacing bowls, when the OPE falls below a certain economically critical level. Such an OPE-awareness program would certainly seem to be one of the first and highest priority energy conservation steps for the farmer to take with respect to reducing the energy used in irrigating crops. It would be expected that with rising energy prices investment in well durability and maintenance will increase and OPE's will trend upward.

The .54 typical OPE figure used for the solar farm is an average figure from the mid-1970's that should tend in the future to be characteristic of only the less well managed farms. An electric plant sized to supply .54 OPE wells should operate with a comfortable capacity margin throughout its life. For example, raising the solar farm OPE to .60 lowers the megawatt-thermal demand from 1.07 MW_t per 100 feet of lift to .93 MW_t per 100 feet of lift, reducing the needed size of the solar plant from 5 MW_t to 4.3 MW_t. If the OPE is raised to .68, megawatt-thermal demand per 100 feet of lift becomes .82, and the needed size of plant falls to 3.8 MW_t. Viewed from the other direction, OPE's of .60 and .68 would permit the base case 5-MW_t plant to supply the representative farm with lifts of 535 and 610 feet, respectively.

Effect of Rising Energy Price on Farm Financial Position

Elsewhere in this thesis it has been found that energy prices would have to rise three to four times relative to the price of other inputs and farm product prices to justify converting wells from electricity bought off the farm to electricity generated on the farm with solar power. Note that this is a relative rise in energy prices compared with other prices and not necessarily an absolute rise above current levels.

Assuming electricity prices were to rise at an annual rate of 7%, other factor and product prices being fixed, then solar power would be expected to become feasible sometime between 1990 and 1998. Now assuming that other farm-related prices experience a 5% rate of rise and holding the rate of rise in the price of electricity at 7%, the relative rate of rise in electricity prices is 2%, and solar use becomes feasible on the Pinal farm sometime between 2020 and 2050. Recall this latter case is quite close to that obtained using the modeling results of Joskow and Baughman (1976).

In the brief analysis performed in this section, it is assumed that the relative rise in the price of energy needed to make solar power feasible does in fact occur. The question to be answered now is: What effect does the higher price of energy have on solar farm net returns? The concern is that the needed energy price rise for solar power to become feasible will squeeze solar farm returns past the limits of profitability. Results such as are given here give only the grossest approximation of the future since the myriad of short-term adjustments to rising energy prices that will take place while moving from the present to the hypothesized future are ignored. In essence the results represent only the immediate effect of 250%, 350%, and 450% rises in the price of energy on the solar farm net returns assuming the rest of the economy remains unchanged.

To compute the effect of the energy price rise the representative farm budget is adjusted at two places; the cost of electricity for the wells and the cost of fuel for trucks, tractors and self-propelled machinery. Other highly energy dependent inputs such as nitrogen fertilizer are not adjusted for the energy price rise.

Table 20 shows the effect of 250%, 350%, and 450% relative rises in the price of energy. The change in nonwater-related variable costs (NVC), water-related variable costs (WVC), the consequent revised net return to crops, net return per acre, and percentage decrease in net return per acre from the base case are computed. The results in Table 20 show that solar farm could survive financially into the high-priced energy future, but at energy prices three times the current price the farm operation would be a marginal one. From the results in Table 20, it does not appear that rising energy prices will ruin Pinal County agriculture before solar electricity generated on the farm can become a feasible alternative; however, there will certainly be some major adjustments, and clearly some farms will become unprofitable.

These results also indicate that Pinal County farmers as typified by solar farm would tend to move into wheat and out of cotton if the prices of these two crops remains relatively stable. The strength of alfalfa in the face of rising energy prices as shown in Table 20 is illusory because most of the nonwater-related variable costs (i.e., fuel costs) are hidden in the assumed custom harvesting and hauling services used for this crop (an artifact of using Hathorn's standard budgets). Cotton production is more sensitive to rising energy prices since not only does it require liberal amounts of water, but also liberal use of fuel consuming machinery. It is the most energy intensive crop of the two basic Pinal County crops examined in this study. Even 50¢/lb. cotton, however, remains marginally profitable up to about a 175% rise in

Table 20. Effect of Rising Energy Prices on Solar Farm Net Returns.

	Alfalfa	Cotton	Wheat
250% rise in energy price:			
Change in nonwater related variable costs (NVC)	$ 1,031.05	$12,552.66	$ 3,583.47
Change in water related variable costs (WVC)	11,231.97	39,180.92	21,480.21
New net returns	4,481.96	(27,108.57)	9,270.04
Net returns per acre	41.88	(56.83)	22.28
Percentage decrease in net returns per acre	73%	203%	71%
350% rise in energy price:			
Change in nonwater related variable costs (NVC)	1,718.42	20,921.10	5,972.45
Change in water related variable costs (WVC)	18,719.95	65,301.52	35,800.35
New net returns	(3,663.39)	(61,599.16)	(7,439.08)
Net returns per acre	(34.23)	(129.14)	(17.88)
Percentage decrease in net returns per acre	122%	334%	122%
450% rise in energy price:			
Change in nonwater related variable costs (NVC)	2,405.78	29,829.54	8,631.43
Change in water related variable costs (WVC)	26,207.93	91,422.13	50,120.49
New net returns	(11,838.00)	(96,088.31)	(24,148.20)
Net returns per acre	(110.65)	(201.44)	(58.05)
Percentage decrease in net returns per acre	171%	466%	171%

energy price and continues to cover variable costs to about a 350% rise in energy prices. Alfalfa at $80/ton ceases to cover variable costs at about a 400% rise in energy prices, while $135/ton wheat ceases to be of even short run interest at about a 450% relative rise in energy price.

Conclusion

All the further considerations discussed in the last part of this chapter have tended to argue against the possibility of using solar-powered wells for pumping groundwater on the representative farm. First it was shown that the operational limitations inherent in relying on sunlight as an energy source are indeed critical to the satisfaction of crop irrigation needs and can only be overcome at considerable expense. Alternative arrangements such as directly steam-turbine driven wells do not have any apparent advantage over the basic solar system arrangement. It also appears that farms such as the representative farm would have considerable room for improving on the efficiency with which irrigation is carried out before having to resort to such drastic action as purchasing a $1.6 million solar plant. Furthermore, it was shown that increasing pumping depths have very little effect on the feasibility of solar pumping. Finally, the future price rises necessary to make solar pumping feasible also bring the viability of the entire farm operation into question.

CHAPTER V

DISCUSSION OF RESULTS AND CONCLUSIONS

Arizona farm operations have been successful up to the present because of plentiful supplies of both water from groundwater supplies and energy. Further, both of these key inputs to Arizona agricultural production have been available at relatively affordable levels. Arizona's farm industry uses not only large amounts of water but concomitantly large amounts of energy, something like 8%, of the State's electrical power supply. How the Arizona farmer might adjust to rising energy prices is an important question for consideration by the State's agriculture infrastructure and its energy planners. This thesis has addressed one part of this larger question through an analysis of the feasibility of using solar power to pump groundwater in Pinal County. Pinal County poses a severe test of solar feasibility because of the artificially low prevailing electricity rates. The 12 mill rate used in this report is only about half the normal rate level elsewhere.

One of the more glamorous technical options for adjusting to higher energy prices is the use of solar power to "free" the farm from expensive and uncertain fossil-fuel-based energy systems. Solar power could be used to generate electricity in a solar-thermal electrical generating plant located on the farm. Despite all the publicity this particular option has received in the popular press, not very much in the way of engineering or economic data have been forthcoming. Unfortunately, the data missing are those needed to perform a truly rigorous financial analysis of the feasibility of solar power.

The lack of firm data can probably only be overcome through building and monitoring the operations of a solar electric plant. The federal government is currently evaluating bids for a solar-thermal prototype plant, including a $100 million proposal from a consortium including Arizona Public Service, Tucson Gas and Electric, and the Salt River Project. A decision regarding these bid proposals is expected early in 1977. Important questions that need answering are:

1. What are the scale economies connected with solar-thermal plants; in particular, what are the economies associated with the collector and heat storage components of the system?

2. What amount of operation and maintenance effort will be required for a solar plant? Can such a plant operate without fulltime supervision and without the care of someone with extensive special training?

3. What is the operating life of the collector section of the thermal-electric solar plant?

4. How and at what cost can solar energy be stored for later use?

The paucity of data on solar power systems has made this study of the feasibility of using solar power to drive irrigation pumps on a representative Pinal County farm difficult. It has forced the study to be rather broad and general. Because of the data problem, it was decided that the best approach to the question was to first construct a representative Pinal County farm to isolate out the needed parameters and then to compute the amount of initial investment that the farm could justify for a system that would free it from the need to purchase off-farm energy. This computation was made within a present-worth framework.

By using this approach, the question of solar system feasibility was answered with a minimum need for specific data concerning solar plant design and costs. It was answered indirectly in the form of a statement that if a solar system designer could create a system that met the justified initial costs based on the representative farm, he would likely find a market for his creation among typical Pinal County farms. For different areas with different electricity rates and lifts, the level of justified initial costs would have to be recomputed.

This upper bound on initial solar plant costs (actually it is a bound on almost any investment for a system of generating electricity on the farm) was presented in Chapter III for a broad range of parameters. For the typical case described there the maximum initial cost came to $404,000 before extracting any penalty for additional operation and maintenance and $259,000 after taking into account extra O&M costs of $16,700.

In Chapter IV, such data on solar-thermal electric generation plants as were available were used to form estimates of solar plant investment costs, the "price" of solar electricity, and the time that seemed most likely for introduction of an economically justifiable system. It was as much the aim of this chapter to indicate what types of analysis and considerations should be included if better data on solar plants become available and what parameters of a solar plant are the most important to solar power feasibility as it was to promulgate the above mentioned estimates.

For the representative solar farm in the typical case, the estimated cost of just a basic solar generating plant was found to be three times its economically justified upper bound ($1.2 million versus $400,000), and once the solar plant was integrated into a solar-powered irrigation system specifically for the representative farm, e.g., with the inclusion of some type of energy storage provision, the estimated cost of the solar plant was found to exceed the justified initial cost by four times. The price on a solar-power irrigation system for solar farm was estimated to be about $1.6 million.

The current selling price of farms in Pinal County, including machinery and improvements, was informally researched by reviewing the classified advertisement of farms for sale in a Pinal County newspaper, "The Tri-Valley Dispatch," from January to September, 1976. It appears from that review that a reasonable estimate of the selling price for the representative farm described in Chapter II is around $1.0 million, considerably less than the estimated $1.6 million cost of the solar plant.

Estimates of the "price" of solar electricity give similar results to those just described. The basic solar plant alone is estimated to supply electricity at a price of around 38 mills/kwh, and the entire solar-powered irrigation system for the representative solar farm carries a "price" of about 50 mills/kwh. The current price of electricity to Pinal farms is 12 mills/kwh. Using estimates of the possible rates of rise in the price of electricity over the coming years gives an estimated time for introduction of solar-powered pumping of around the year 2025.

It should be noted that the assumptions behind the above estimates are generally favorable toward the solar irrigation concept. All these estimates should be looked at as being from the viewpoint of an advocate of solar power. With this in mind, the wide margin, viewed in terms of dollars or years, by which solar-thermal power misses being economically feasible for the representative Pinal County farm perhaps explains the difficulty encountered in locating any detailed data on solar systems for this study.

Despite the large amount of money Pinal farmers spend on electricity annually for pumping irrigation water and the likely increase in this cost over time, the use of solar power on Pinal County farms is improbable. It is possible, however, to conceive of a future course of events that could lead to the adaptation of solar power. Solar power cannot be ruled out for the application considered here for all time on economic grounds, but it faces a not very attractive future prospect.

Governmental agencies may want to intervene in the "natural" economic flow of events considered above on the side of solar power out of a desire to conserve energy from depletable resources, a desire to avoid the environmental costs of some competing energy alternatives, or a desire to preserve the productive Arizona agricultural industry. Also, solar power may be an attractive means of supplying the power needed to open up remote semiarid regions of the world to modern agricultural production through the tapping of local groundwater supplies. Arizona farms would be convenient places to test out such concepts.

The use of solar energy for pumping groundwater on Pinal farms would likely require fairly large governmental involvement both for technical development of the system and for financial incentives for its introduction.

There are many adaptations Arizona farmers can make to rising energy price before they must need to consider solar power. These adaptations are generally along the line of energy and water conservation on the farm. Water conservation practices can reduce farm water pumpages, and thus farm electric bills, by a considerable amount. Therefore, the time when solar power might be feasible for agricultural use in pumping groundwater seems so far off that only a very low level research and monitoring effort is currently warranted.

APPENDIX

PRODUCTION BUDGETS FOR SOLAR FARM

The following charts present the detailed crop budgets constructed for the representative Pinal County farm described in Chapter II of this thesis.

Cotton Production Budget

Equipment Used: Type	Annual Hours of Use	Chargeable Fixed Costs	Related Nonfuel Variable Costs
70-hp tractor	910	$ 3,514.42	$ 844.54
100-hp tractor	969	5,179.75	1,063.96
half-ton truck	1,019	2,982.92	1,263.56
cotton picker	893	19,992.00	11,008.39
cultivator	406	453.00	432.82
disk offset	389	1,058.75	906.37
harrow	60	73.00	13.20
landplane	124	547.26	166.16
lister 7-bottom	86	337.00	86.86
moleboard plow	142	636.00	299.21
mulcher	142	427.00	200.83
planter	108	366.00	208.14
cotton trailers	1,678	4,408.00	520.18
rood	286	2,510.00	1,865.13
fertilizer spreader	18	105.00	13.32
rowbuck	32	176.76	8.32
stalk cutter	86	592.00	67.84
TOTALS		$45,358.86	$19,009.83

Materials Used: Type	Amount	Variable Cost
Fertilizer 16-20-0	44.1 tons	$ 7,441.20
Herbicide (trefaln)	661.5 pints	2,322.94
Seed and PCNB	5,724.0 pounds	2,022.48
Insecticide (parathion)	2,712.0 pints	3,968.64
Insecticide (fundal)	1,005.75 pints	1,659.96
Insecticide (lannate)	3,882.0 pints	3,734.64
Herbicide	3.57 tons	2,752.29
Defoliant	1,908.0 gallons	1,588.41
Diesel fuel	14,691.6 gallons	5,692.99
Gasoline	5,137.2 gallons	2,675.45
TOTAL		$39,821.51

2,403 acre-feet of Water:	Cost
Electricity	$26,120.60
Operation & maintenance	8,314.38
Fixed Cost Amortization	15,114.87
TOTAL	$49,549.86

Cotton Production Budget -- Continued

Custom Work Used:	Cost
Ginning	$67,291.85
Other	18,778.68
TOTAL	$86,071.23
Short-term credit	4,404.96

Labor Costs:	
Related to Irrigation	$ 7,372.62
Other labor	13,007.70
TOTAL	$20,380.32

Cotton Production Cost Summary:	Cost
Machinery-related chargeable fixed costs	$45,358.06
Well-related chargeable fixed costs	15,114.93
TOTAL CHARGEABLE FIXED COSTS	$58,472.93
(Nonwater related variable costs)	
Labor	$ 13,007.70
Maintenance	19,009.83
Credit	4,404.96
Custom work	86,071.23
Materials	39,821.51
TOTAL	$161,775.23
(Water related variable costs)	
Electricity	$ 26,120.61
O&M	8,314.38
Labor	7,372.62
TOTAL	$ 41,807.61

Wheat Production Budget

Equipment Used:	Annual Hours of Use	Chargeable Fixed Costs	Related Nonfuel Variable Costs
70-hp tractor	118	$ 455.72	$ 99.77
100-hp tractor	326	1,743.75	357.95
1/2-ton truck	420	1,229.47	520.80
combine	124	6,586.00	1,159.40
disk offset	228	620.56	531.24
lister 5-bottom	98	299.00	87.22
grain drill (14-ft)	94	506.82	307.85
fertilizer spreader	14	81.67	10.36
rowbuck	10	50.48	2.40
TOTALS		$11,573.47	$3,076.99

Materials Used:	Amount	Variable Costs
fertilizer 16-20-0	41.6 tons	$ 9,566.59
wheat seed	31.2 tons	11,681.28
61 lbs. NH_3	50.75 tons	10,400.00
gasoline	2,080.0 gallons	1,083.26
diesel	3,369.6 gallon	1,305.72
TOTAL		$34,036.85

1317.4 acre-feet of water:	Cost
electricity	$14,320.14
operation and maintenance	4,558.20
fixed cost amortization	8,286.45
TOTAL	$27,164.79

Custom Work Used:	
hauling	$ 2,941.12
short-term credit	1,576.74

Labor Costs:	
Related to irrigation	$ 4,043.52
Other labor	1,996.80
TOTAL	$ 6,039.32

Wheat Production Budget -- Continued

Wheat Production Cost Summary:	Cost
Machinery-related chargeable fixed costs	$11,573.47
Well-related chargeable fixed costs	8,286.45
TOTAL CHARGEABLE FIXED COSTS	$19,859.92
(Nonwater related variable costs)	
Labor	1,996.80
Maintenance	3,076.99
Custom work	2,941.12
Credit	1,576.74
Materials	34,036.85
TOTAL	$43,628.50
(Water related variable costs)	
Electricity	$14,320.14
O&M	4,558.20
Labor	4,043.52
TOTAL	$22,921.86

Alfalfa Production Budget

Equipment used:	Annual Hours of Use	Chargeable Fixed Costs	Related Nonfuel Variable Costs
70-hp tractor	73	$ 281.92	$ 61.72
100-hp tractor	202	1,176.34	241.56
1/2 ton truck	252	737.68	312.48
chisel plow	64	178.00	33.92
disk offset	73	198.69	170.09
float	28	322.00	12.88
land plane	55	242.73	73.70
vibra-shank	26	277.00	21.58
grain drill	26	140.18	85.15
fertilizer spreader	4	23.33	2.96
scraper	5	212.00	1.20
TOTALS		$3,762.67	$1,017.24

Materials used:	Amount	Variable Cost
Fertilizer 11-48-0	10.7 tons	$2,086.50
Seed	29.9 cwt	2,990.00
Insecticide (thimet)	142.67 pts	352.03
Insecticide (furadan)	107.0 pts	472.94
Diesel fuel	1669.20 gal.	646.81
Gasoline	1251.90 gal	651.99
TOTAL		$7,200.27

728.6 acre-feet of water:	Cost
Electricity	$ 7,919.68
O&M	2,520.96
Fixed cost amortization	4,582.89
TOTAL	$12,754.63

Custom Work Used:	
Cubing	$18,725.00
Insecticide application	385.20
TOTAL	$19,110.20
Short-term credit	513.60

Alfalfa Production Budget -- Continued

Labor Costs	Cost
Related to irrigation	$3,719.21
Other labor	3,830.34
TOTAL	$7,549.55

Alfalfa Production Cost Summary:

(Note that the following costs have been weighted to spread the cost of alfalfa stand establishment over three years.)

Machinery-related chargeable fixed costs	$ 1,633.14
Well-related chargeable fixed costs	4,332.97
TOTAL CHARGEABLE FIXED COSTS	$ 5,966.11
(Nonwater related variable costs)	
Labor	1,286.09
Maintenance	479.36
Short-term credit	389.81
Custom work	19,110.20
Materials	3,383.20
TOTAL	$24,648.33
(Water related variable costs)	
Electricity	7,487.98
	2,383.48
	2,659.46
TOTAL	$12,530.92

LIST OF REFERENCES

Arizona Agriculture Experiment Station, Consumptive use of water by crops in Ariozna, The University of Arizona, Tucson, Technical Bulletin 169 (reprint), August 1968.

Arizona Bureau of Mines, Mineral and water resource of Arizona, Bulletin 180, Tucson, Arizona, 1969.

Arizona Crop and Livestock Reporting Service, 1975 Arizona Agricultural Statistics, Bulletin S-11, Phoenix, Arizona, March 1976.

Arizona Water Commission, Summary: Phase I -- Arizona state water plan, inventory of resource and uses, Phoenix, Arizona, July 1975.

Conn, Robert W. and Gerald C. Kulcinski, Fusion reactor design studies, Science, 193:4254, August 20, 1976.

Firch, Robert, Professor, Department of Agricultural Economics, The University of Arizona, Tucson, personal communication, 1974.

Frank, Helmut, in Arizona Statistical Review, Valley National Bank of Arizona, Phoenix, 31st ed., p. 38, September 1975.

Grant, Eugene L. and W. Grant Ireson, Principles of engineering economy, (5th ed.), The Ronald Press Co., New York, 1970.

Hathorn, Scott, Jr., Arizona pump water budgets, Pinal County 1976, Department of Agricultural Economics, The University of Arizona (analogous reports are issued for Pima, Cochise, and Maricopa Counties), February 1976.

Hathorn, Scott, Jr., Charles Robertson, James Little and Sam Stedman, 1976 Arizona field crop budgets, Pinal County, Department of Agricultural Economics, The University of Arizona, Tucson, April 1976.

Hathorn, Scott, Jr. and N. Gene Wright, Arizona farm machinery costs for 1976, Department of Agricultural Economics, The University of Arizona, Tucson, January 1976.

Joskow, Paul L. and Martin L. Baughman, The future of the U. S. nuclear energy industry, The Bell Journal of Economics, Vol. 7, No. 1, Spring 1976.

Larson, Dennis, Professor, Department of Soils, Water and Engineering, The University of Arizona, Tucson, personal communication, 1976.

Manne, Allen S., Electricity investments under uncertainty: waiting for the breeder, in Energy: Demand, Conservation and Institutional Problems, Michael S. Maerakis, Ed., MIT Press, Cambridge, Massachusetts, 1973.

Morin, George, Lecturer, Department of Soils, Water and Engineering, The University of Arizona, Tucson, personal communication, 1976.

Nelson, Aaron G. and Charles D. Busch, Cost of pumping irrigation water in central Arizona, Arizona Agriculture Experiment Station, Technical Bulletin 182, The University of Arizona, Tucson, April 1967.

Ozsabuncuoglu, Ismail, Economic impacts of alternative irrigation systems under increasing irrigation water costs in southwestern Arizona, Doctoral dissertation in preparation, Department of Agricultural Economics, The University of Arizona, Tucson, 1976.

Sands, Charles D., II, Research Associate, Department of Soils, Water and Engineering, The University of Arizona, Tucson, personal communication, 1976.

Strickland, James H., Merton E. Fewell, Steven O. Heard, Prashant D. Parikh and Thomas E. Burnette, The on-site utilization of solar energy for agricultural operations in Texas, Prepared for the Office of the Governor under contract GAEC IAC (76-77)-1144, Texas Tech University, Lubbock, August 1976.

Taylor, B. Brooks, Cooperative Extension Service, The University of Tucson, personal communication, July 1976.

U. S. Department of Agriculture, Farm Credit Administration, 42nd Annual Report of the Farm Credit Administration and the Cooperative Farm Credit System, 1974-75, Government Printing Office, Washington, D. C., 1975.

U. S. Department of Agriculture, Agricultural Statistics, 1976, Government Printing Office, Washington, D. C., Stock No. 001-000-03437-5, 1976.

U. S. Department of Commerce, 1969 Census of Agriculture, Chapter 9: irrigation and drainage on farms, Social and Economic Statistics Administration, Bureau of the Census, Washington, D. C., July 1973.

Western Interstate Nuclear Board, Impacts of Alternative Electricity Supply Systems for California, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, Berkeley, May 1976.