AN ANALYSIS OF INCENTIVES FOR INDUSTRIAL INVESTMENT IN SOLAR ENERGY IN DEVELOPING COUNTRIES**

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1 INTRODUCTION

It is by now well recognized that most developing countries, in particular the large number of oil importing developing countries, face difficult energy choices following a decade of rapid escalation of world oil prices. Historically, what may be termed the "petroleum route" to development, was the major avenue followed by most developing countries in obtaining the necessary energy inputs required to fuel their developmental and modernization plans. The dilemma for developing countries is that, unlike the industrial countries, they need to increase their energy consumption significantly at a time when the cost of acquiring energy has also risen significantly. However, both developing and industrial countries share the objective of increasing the efficiency of energy use.

Urbanization and industrialization, the traditional ways out of a subsistence rural economy, are both energy intensive. Even the modernization of the rural economy via the raising of agricultural productivity and the introduction of non-farm activities requires substantial additional inputs of energy capable of being utilized more efficiently and productively.

Given this difficult situation and its implications for the external finances of developing countries,† their economic growth prospects and, eventually, their political and social stability it is not surprising that there has been a resurgence of interest in the utilization of energy resources, such as the renewable energy sources which are locally available and with which the developing world, by and large, is well endowed.

Although renewable resources, such as solar and wind, are available, in a sense, "free of cost" the associated conversion equipment needed to

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†The World Bank has estimated that the cost of the net oil imports of the Oil Importing Developing Countries in constant U.S. dollars has risen almost tenfold in the past decade, and that, unless a major effort is made to reduce oil consumption, it will more then double by 1990.[1]

transform them into usable energy forms is definitely not. Most renewable energy technologies are more capital-intensive than conventional energy technologies. Cost comparisons are therefore initially dependent on the cost of capital. However, solar technology has a zero fuel cost and would add minimally to balance of payments problems after capital investment is repaid. However, it will not be possible to take advantage of the indigenous and renewable characteristics of solar energy if the initial investment is "uneconomical" from the perspective of a national planner.

Planners in developing countries are often confronted with a bewildering and confusing array of assessments on the economic viability, the technical feasibility, the logistical complexity and the implementation capability of most renewable energy technologies vis-a-vis the conventional alternatives. The objective of this paper is limited to examining, in some detail, the impact of government investment incentives on the comparative economics of solar energy and oil. We focus on one renewable energy technology, which appears to be technically feasible in the near-term and economically viable in the mid-term. This technology is solar industrial process heat.

A variety of policy measures can be used by government to provide incentives for industries to invest in solar energy technologies. Examples of these include subsidies, tax credits and low interest loans. Moreover, most governments in developing countries play a large role in energy policy decisions and usually have the necessary mandate to set "rational" energy prices.

Using well-established cash-flow procedures, we show the relative importance of the various economic and financial parameters in determining the internal rate-of-return[3] on an investment in renewable energy technology. We show that a combination of enlightened financial policy and sound

engineering using either available or near-term technology can produce attractive investments in fuel saving SIPH systems in many significant energy-consuming industries the developing world. However, it is clear that the economic viability of solar energy in developing countries is crucially dependent on the price of oil.

We have not carried out a detailed analysis of the foreign exchange implications of substituting solar hardware (part of which may be imported) for imported oil. Incorporating the foreign exchange component of capital cost is highly country, technology and project specific, and this exercise should be performed by developing country planners before any major investment decisions are made. As a first approximation, this paper assumes that the capital costs for the solar hardware includes the premium on imported components.

Our choice of solar IPH as a case study is dictated in part by our belief that solar IPH systems can lead to substantial oil savings in a large number of developing countries, particularly in food processing, textile, and other industries which require large amounts of low-to-medium-temperature hot water and steam. We also feel that the relevant policy actions on the part of national governments, international lending institutions, and other policy- and decision-makers which will play a significant role in stimulating the development of solar options are probably a great deal easier to implement within the organized industrial sector. However, the choice of solar IPH is primarily intended as an example of a case study of one particular application. We do not mean to downplay the potentially very important role renewable energy can play in meeting other essential energy needs pertaining to economic and social development in the developing countries such as, for example, the energy needs of rural households or of food production.

2 THE INTERNAL RATE OF RETURN AS AN INSTRUMENT FOR INVESTMENT DECISIONS

Comparison of the cost of delivered energy between renewable and fossil fuel systems is rarely straightforward. The delivery of solar-derived energy is a capital-intensive activity. The unit capital cost of equipment to transform solar energy to industrial process heat can be as much as ten times the cost of equipment to transform fossil fuels to useful process heat. A central issue is the extent to which fuel savings can amortize the solar equipment investment. To account for the complex financing and tax considerations that are important in a capital-intensive investment, a detailed cash flow analysis is needed to accurately portray the economic position of solar technologies relative to conventional fuel-based technologies.

To evaluate investments in renewable energy systems, government, industry, and international financial institutions such as the World Bank will require detailed calculations of the internal rate of return for the project. In the case of solar industrial process heat systems, it is the rate gained by investing in solar equipment rather than continuing to buy fossil fuels. This rate can also be compared to the rate of return that may be gained by other investments of the same money.

Investment decisions are made by comparing the cost of an investment project, the expected returns (yearly cash flow) and the price of capital. The price of capital can be taken as either the rate of interest at which the firm obtains loans or the rate of return that investors expect on the equity for the project. The present value (PV) is an amount which, taking into account the earning power of capital over time and the difference in time between the present and some future date, would be equivalent today to an expenditure or receipt at such a future date. The PV is the result of

discounting future cash flows (positive or negative) to the present by the appropriate discount rate (time value of capital).

The Internal Rate of Return (IRR) is defined as that discount rate, which when applied to a stream of benefits and costs reflected in the cash flow of a project, produces a zero net present value:[3]

$$PV\ (IRR) = \sum_{t=0}^{N} NCF(t)/(1 + IRR)^t = 0$$

where NCF is the net cash flow and t stands for time.

A variety of factors determine the IRR. With renewable energy technologies many of these factors will vary considerably from one location to another and also over time as these technologies evolve and become widely commercialized. Among these factors are the capital and operating costs of the system, system performance, the financing details of system ownership, tax status, and credits, and the rate of increase in the real prices of fossil fuels.

Each solar IPH installation is a unique engineering, economic, and financial venture. Even when two solar IPH installations have identical technical performance and costs, they can have completely different investment characteristics. For instance, the difference between an available 25 percent tax credit for one installation and no tax credit for the other can be the difference between a project with an attractive rate of return and one with a very low or even negative rate of return. We have examined the circumstances under which a solar IPH installation would be an attractive financial investment. Because of the large number and wide ranges of cost and financial variables, there is no <u>unique</u> combination of technical and

financial factors which will produce an attractive investment. However, there is a range of realistic financing circumstances, the physical availability of solar insolation and equipment performance and costs for which an attractive return on investment can be achieved.

We have used a conventional economic cash flow analysis to evaluate a number of solar industrial process heat (SIPH) systems. We assume that the capital investment in solar equipment is amortized strictly by fuel savings.

This analysis reveals the relative importance of various economic and financial parameters and suggests which policy measures will most accelerate or impede the introduction and diffusion of SIPH and other solar energy systems. For instance, the heavy subsidization of petroleum products such as fuel oil, diesel and kerosene practiced in many developing countries will inhibit private investors from investment in renewable energy systems. In contrast, as is to be expected, investment tax credits, direct rebates, accelerated depreciation, and preferred interest rates for renewable energy systems will help accelerate the pace of commercial development and use of solar products.

3 FINANCIAL ANALYSIS PROCEDURES FOR RENEWABLE ENERGY SYSTEMS

A number of technical, economic, and financial factors combine to determine the investment characteristics of a renewable energy system. These factors can be combined in a computerized discounted cash flow analysis to yield the internal rate of return for the system.

Some of the economic factors are technical or environmental in nature, such as the installed cost per square meter of solar collector or the available solar energy. Other economic factors are policy related, such as the local price of fuels and the rate of increase in fuel prices. Important financial factors, subject to some degree of policy control, include the debt interest rate, depreciation life and method, investment tax credits, and effective rates of protection accorded to specific industries and products. The economic and financial factors used to compute the internal rate of return for the renewable energy systems considered in this report, solar IPH technology, are listed in Table 1.

3.1 Computer-Based Financial Analysis for Solar Industrial Process Heat

A number of computer programs, some quite complex, have been designed to analyze the effects of these factors on the rate of return. The Solar Energy Research Institute (SERI) has developed PROSYS/ECONMAT[5] to simulate SIPH system performance on an hour-by-hour basis and to calculate the resulting energy costs. These programs require detailed insolation data,[6] and run on a mainframe computer. Such programs are extremely useful in assessing the actual performance of a proposed system on an hour-by-hour basis over the course of a year. They can provide good estimates of the requirements for backup fuels during the year, indicate the best (least disruptive) periods for scheduled maintenance of the solar energy components of the system, and so forth. However, such a detailed analysis is not required in order to

Table 1
Economic and Financial Factors Used to Compute the Internal Rate of Return for a SIPH System Investment

Economic Factors (System Related)

- System cost per m^2 of aperture
- Available insolation
- Net system efficiency (solar)
- Average capital cost [$/kW(th)]
- Overhead and Maintenance Costs

Economic Factors (Policy Related or Political)

- Prices of competitive fuels
- Rate of increase in real fuel prices (including changes in the dollar exchange rate of local currencies)

Financial Factors (Subject to Policy Controls)

- Percent equity
- Debt interest rate
- Investment life
- Taxes and insurance
- Property tax escalation rate
- Percent of initial investment allowed for depreciation
- Salvage value at end of plant life
- Depreciation life
- Method of tax depreciation (DDB, SYD, straight line)
- Marginal tax rate
- Investment tax credits
- Sinking fund interest rate
- Negative cash flow accounting method

determine the relative impacts of system costs, performance, and economic factors on the levelized cost of solar-derived heat or on the internal rate of return.

The analysis described in this paper was conducted using a computer program designed for use on a personal-sized computer, using simplified insolation data[7] and performance algorithms to examine the important variables in SIPH economics. The program, originally created at Teknekron Research, Inc., was further developed at Brookhaven National Laboratory and also modified to run on a mainframe computer, permitting rapid examination of a large number of combinations of financial and economic parameters. The

main ingredients (input parameters and computed output) are shown in Figure 1. Details of the financial model are found in Appendix A.

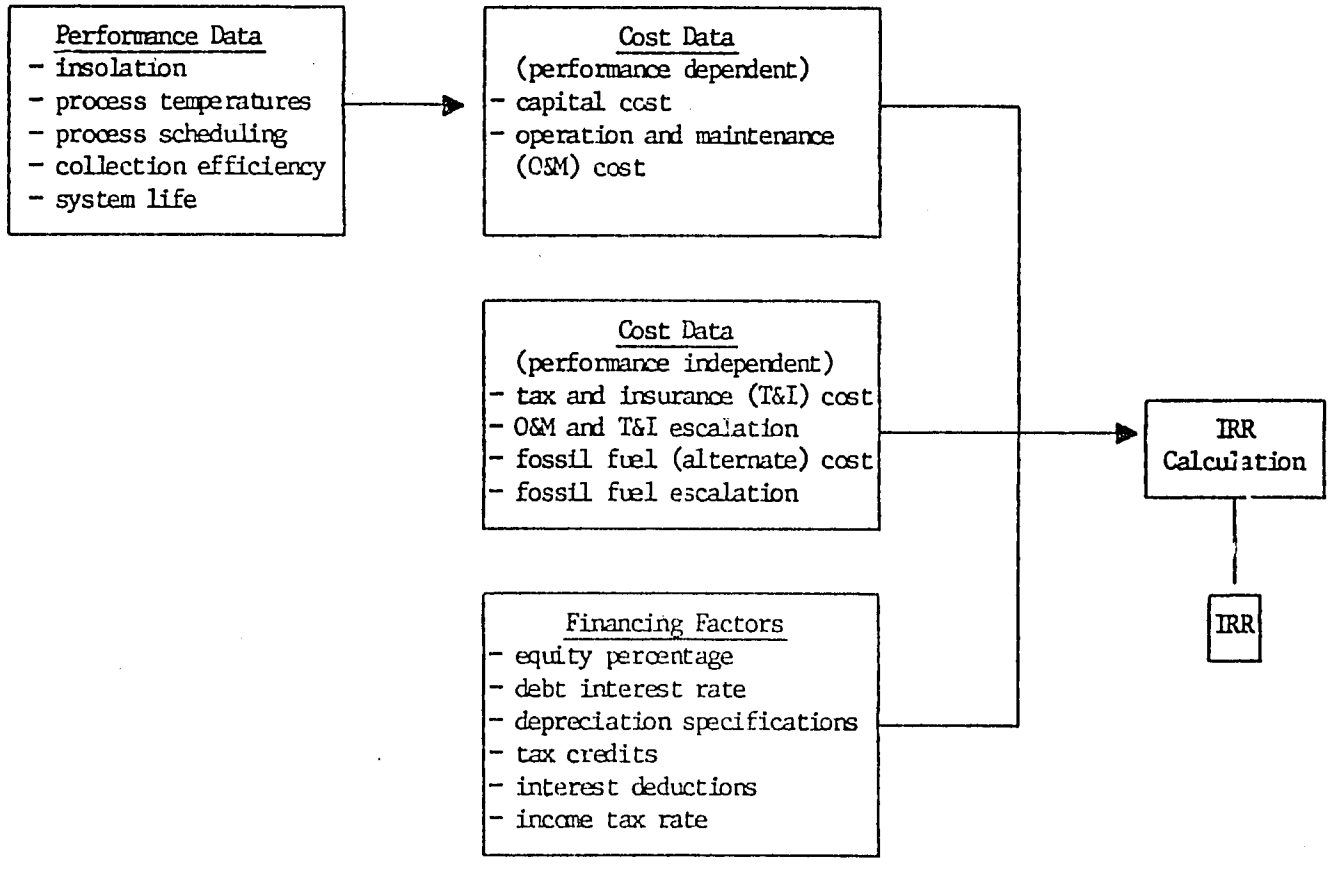

Figure 1. Determination of Internal Rate of Return for a Solar Industrial Process Heat System.

4 INDUSTRIAL INVESTMENT IN SIPH: FINANCIAL CONSIDERATIONS AND UNCERTAINTIES

As pointed out earlier, a broad array of technical, environmental, economic, and financial factors which determine the investment characteristics of a solar energy system. The technical factors include the system's solar energy collection, conversion, and thermal exchange efficiencies. These in turn are affected by the industrial process scheduling and process temperature requirements for the complete IPH installation. System and component lifetimes and requirements for maintenance also affect the system costs. Environmental factors affecting performance include the availability of direct and diffuse solar radiation as a function of time, and environmental stresses such as wind loading and moisture, salt, and other corrosive elements in the atmosphere. The environmental stresses can decrease the life of some of the SIPH system components.

There is no simple generalization which can be made about the costs of SIPH systems. This is because the economics of the hardware and the financial investment environment for such an installation can vary enormously from one region to another. For instance, the capital cost per average kW(th) of useful delivered heat will depend on the patterns of available solar energy, the specific engineering design[8] of the collection, conversion and heat transfer subsystems, the heat load profile of the specific industrial process,[9] and the manner in which the entire system is operated. Installed costs of SIPH systems, per square meter of system aperture, can easily range from $500 to $2000, with projected costs for some systems declining to perhaps $200. (All costs are in current 1981 dollars.) While the net efficiency of conversion from incident solar radiation to useful process heat

can in principle be as high as 0.35 (annual average), many currently operating commercial prototype SIPH systems are experiencing annual efficiencies in the range of 0.10 to 0.30. Available solar radiation can range from 2.0 to 6.0 kWh/m^2-day (annual average) for global insolation, and from perhaps 3.0 to 8.0 kWh/m^2-day for the tracked, direct beam (focusable) solar radiation. The range of available solar radiation is summarized in Table 2.

As a base case, we assume a concentrating and tracking solar collection system, operating in an insolation environment of 6 kWh/m^2-day, a net efficiency of 0.3, and an installed system cost of \$300/m^2, which yield a capital cost of \$4000/kW(th). This could be achieved with careful system design and operation in an LDC environment with widely encountered solar radiation patterns, and with local government policies which would minimize duty, delays, and other factors which can increase costs.

In this case we are assuming that the technology has become fully mature, that the information and experience required to design and operate SIPH systems with something close to the maximum attainable efficiency is widely available, and that policies are in effect to encourage both local manufacture and use of imported hardware, as appropriate, to harness renewable energy flows. On the basis of previous experience with the emergence of a commercial industry for solar water heating in the U.S., Japan, and Europe, such a process can be expected to take the better part of this decade, at least.

While solar energy systems for production of process heat above 100°C are unlikely to be used in regions which are not very sunny, there is still a substantial range[11] in the available direct and total solar radiation in

Table 2
Characteristics of Solar Radiation As an Energy Source[10]

The Solar Constant	1353 W/m^2
Effective Radiation Temperature of the Sun	5760 K
Maximum Direct Beam Irradiation at Sea Level	1000 W/m^2

Region, Irradiance		kWh/m^2-Day	W/m^2 (Average)
Tropics deserts		5 - 6	210 - 250
Temperate zones	(Annual average horizontal)	3 - 5	130 - 210
Less sunny regions (e.g., northern Europe)		2 - 3	80 - 130
Average annual direct beam irradiance in sunny regions		7 - 8	290 - 330
Monthly average direct beam radiation in sunny, arid regions		5 - 10	210 - 420

regions generally considered "sunny."* All of these factors conspire to yield a capital cost range for SIPH systems of $1700 to $20,000 per average thermal kilowatt of delivered process heat (Table 3).

If some of the equipment, such as high-efficiency tracking solar concentrators, must be imported from outside the country, formal and informal import duties, customs clearance periods and fees, and so forth can widen the capital cost range even further. As an example, pressure from U.S., Japanese, and European manufacturers of photovoltaic arrays, and from their local distributors, recently led to one LDC government reclassifying these arrays as electronic equipment. This resulted in a decrease in duty from over 100% to about 5%.

Other uncertainties in SIPH economics are due to:

- Wholesale price variations for similar equipment produced by different manufacturers;
- differences in technical performance of various solar collection, conversion and heat transfer elements;

*In sunny arid desert regions, the direct beam component of the solar radiation at the ground can be as high as 85%. In sunny tropical regions near the equator (West Java, for instance), the direct beam component may be as low as 40% over the year, even though the total sunlight reaching the ground is as much as 85% of that experienced in the sunniest deserts.

Table 3
Factors Contributing to the Average Capital Cost of a Solar Industrial Process Heat Facility

Factor	Poor	Fair	Good	Base Case	Superb	
Sunlight	2	3	5	6	8	kWh/m^2-day (annual av)
System Cost	2000	1000	500	300	200	$\$/m^2$ of aperture, installed
Efficiency	0.10	0.15	0.25	0.30	0.35	Net conversion of incident solar radiation into useful process heat
Capital Cost [$\$10^3/kW(th)$]	240	53	9.6	4.0	1.7	Cost per annual average net thermal capacity

- uncertainty in the rate with which improvements in technical design, industrial production procedures, and manufacturing scale will reduce the wholesale prices of solar IPH components;
- wide variations in system efficiency due to differences in process requirements for heat as a function of time, availability patterns of solar radiation, engineering sophistication of the complete solar IPH installation, operating procedures for the plant, and time required for routine and nonroutine operation and maintenance;
- bid spreads from different engineering firms, even when the wholesale price of the solar and nonsolar components is well defined; and
- cost overruns due to a lack of widespread international experience with commercial solar IPH components and installations.

Variations in the financial factors reflect differences among regions and countries in financial practices, tax credits for solar energy systems, special depreciation and tax status for such systems, prevailing interest rates, availability and price of traditional fuels for IPH facilities, and so forth.

5 FINANCIAL ANALYSIS OF SOLAR INDUSTRIAL PROCESS HEAT

For analyzing a base case and to show that investment in SIPH in developing countries is close to being economical we chose to use the example of a brewery in a developing country. Most of the countries in the world produce beer; an even larger number have general food and beverage processing needs which require significant amounts of low temperature process heat. Because of the widespread need for such processing, we felt that a solar industrial process retrofit to a developing country brewery would be a useful example. In this example we have tried to use reasonable estimates of the factors which determine the rate of return on such an investment. The internal rate of return and its sensitivity to various changes in the important financial and economic factors are calculated.

5.1 Base Case: Solar Brewery in an LDC

In our example, about twenty-five percent of the process heat used in the brewery is assumed to be provided by a solar industrial process heat system. We assume that the brewery produces 14 million cases of beer (84 x 10^6 liters) each year and works around the clock, every day of the year. About one-half of the thermal energy required for the plant is used to pasteurize 14 million cases of beer. This requires about 18,000 GJ of heat energy supplied at 65°C. To reduce fuel bills substantially while maintaining a fossil-fired backup system in place, one-half of the pasteurization process heat will be supplied with a solar system providing 9,000 GJ of solar-derived heat annually.

The brewery location receives an average of 7.25 GJ of solar radiation per square meter each year on a surface tilted at the angle of the brewery latitude. Since a flat-plate collector can deliver 45% of this solar energy as heat at 65°C, 2760 square meters of collectors are required to supply

9,000 GJ of heat per year. We assume that, since this is only half the heat needed for pasteurization and since most of the pasteurization can be scheduled during the day, all of this heat can be used. Table 4 summarizes the specifications of our example.

In this example, we have used optimistic but attainable costs for such a flat-plate collector solar IPH system. At $225 per square meter of collector for the installed costs of the system, the system capital cost is about $2200 per average kW(th). The average rate of solar thermal energy production over the year is about 286 kW(th). Combining the performance, economic, and financial factors for this investment yields an internal rate of return of about 12.7 percent which is a fairly large value (Table 5). As we shall see, this rate of return is due mainly to the assumption of capital cost. It should be noted that in all other analyses, we have chosen a capital cost of $4000/kw(th).

5.2 PARAMETRIC FINANCIAL ANALYSIS

A sensitivity analysis was conducted to explore the relative importance of various economic and financial parameters in the determination of the internal rate of return (IRR) and to analyze the impact of the various

Table 4
Summary of Specifications for Solar IPH System for Zimbabwe

Parameter	Specified Value
Insolation	7.5 GJ/m^2-yr on surface tilted at angle of latitude
Process Temperature	65°C
Process Scheduling	24 hour continuous, with full use of solar system during days, all solar-generated heat assumed to be collected and used
Solar Collection and Delivery Efficiency	45% at 65°C
Required Collector Area	2760 m^2
Installed System Cost	$225/m^2

Table 5
Economic and Financial Parameters for the Base Case

Parameter	Value
Capital Cost	$2200/kW(th)
Percent Equity	50
Debt Interest Rate	15% per year
Investment Life	20 years
Year 1 Cash Flow[1]	$214 (based on $30/bbl oil)
Cash Flow Escalation Rate[2]	11%/year
Taxes and Insurance[3]	$44/year
Operation and Maintenance[3]	$44/year
T&I Escalation Rate	8%/year
O&M Escalation Rate	8%/year
% Initial Investment Allowed for Depreciation	100%
Salvage Value	None
Depreciation Life	7 years
Depreciation Method	Straight Line (SL)
Marginal Tax Rate	48%
Investment Tax Credit	25%
Cash Flow Method	Conventional (no sinking fund)
IRR	12.7
Discounted Payback Period	18 years

[1]The first-year cash flow is based on displacement of oil costing $30 per barrel and normally converted to process heat with a net efficiency of 70%.
[2]The nominal inflation rate is taken as 8%, with oil prices assumed to rise at 11% per year, or 3% per year above inflation.
[3]O&M costs and T&I costs are each assumed to be two percent per year of the base case capital cost.

incentives for a solar industrial process heat (SIPH) system investment. Six parameters were initially chosen for variation. These include the capital cost of the SIPH system, the current price of competitive fuels such as oil, gas, and coal, the rate of increase in the real price of the competitive fuels, the debt interest rate, the debt/equity ratio, and the investment tax credit. Other parameters were held fixed at the values chosen for the financial base case. Table 6 indicates the range of values used for the variables picked for this analysis.

Table 6
Economic and Financial Parameters Used in the Financial Analysis the Solar Industrial Process System

Factor	Range
System Cost ($/m^2)	$100 - $1000 ($960 - $4000/kW)
Fuel Cost ($/GJ)	$5 - $10 ($30/bbl-$60/bbl of oil)
Investment Tax Credit (%)	0 - 50
Debt Interest Rate (%/year)	5 - 25
Percent Equity	20 - 100
Fuel Escalation Rate (%/year)	8 - 15
Depreciation Period (years)	1 - 10

This financial analysis is indicative of the various combination of economic and policy variables which will determine the final IRR for a SIPH project. Many of the fixed values for parameters such as debt interest rate, investment life, marginal tax rate, and tax and insurance costs are representative of conditions in many developing countries. For regions where these parameters take on very different values, the impact of these different values on the IRR will have to be taken into account.

5.3 RESULTS OF POLICY ANALYSIS

5.3.1 IRR vs Capital Costs and Rate of Oil Price Increases

In this example (Table 7, Figure 2), a range of rates of increase for oil prices from 0 to 6 percent per year above inflation is used. Oil is assumed to cost $30/bbl. For the least expensive system, the IRR is attractive for oil price increases above 3%. However, for the base case and the more expensive case, this is not so. If a three percent rise in real oil

Table 7
Internal Rate of Return (percent/year) for the Base Case, as a Function of Rate of Oil Price Increases and Capital Costs

Oil Price Increase (Percent per Year)	Capital Cost ($/kW) 2500		4000		6000
0.0	-1.1	(15.8)	-80.0	(2.3)	
2.0	6.0	(19.8)	-5.1	(7.8)	-28.1
3.0		(21.6)	-1.3	(10.0)	
4.5	11.7	(24.1)		(12.8)	-7.3
6.0		(26.4)	6.2	(15.4)	-0.8

Note: Numbers in parentheses refer to oil price of $45/bbl.

prices is assumed in the financial analysis, the projected IRR is around zero. If no increase in oil prices (or the prices of the alternative fuels) is assumed, the return on investment is negative. For the most expensive of the systems considered, even an annual rate of increase of 6 percent in real oil prices would be insufficient to make the investment attractive.

5.3.2 IRR vs Capital Costs and Oil Prices

In this example (Table 8, Figure 3), the base case cost of $4000 per kW(th) is used, along with a 3 percent per year increase in real oil prices. If $30 per barrel is assumed for the current oil price, the IRR is negative for capital costs above $4000 per kW(th). At $45 per barrel the IRR is positive for capital costs less than $6000 per kW(th). For $60 per barrel, the IRR is positive for capital costs as high as $8500 per kW(th). In order to secure an IRR in excess of 20 percent, the capital costs must be below $2500 per kW(th) for oil prices of $45 per barrel. The higher oil prices are likely to prevail soon for most countries, and a capital cost of $2500 per kW(th) could well be achieved by the end of the 1980's.

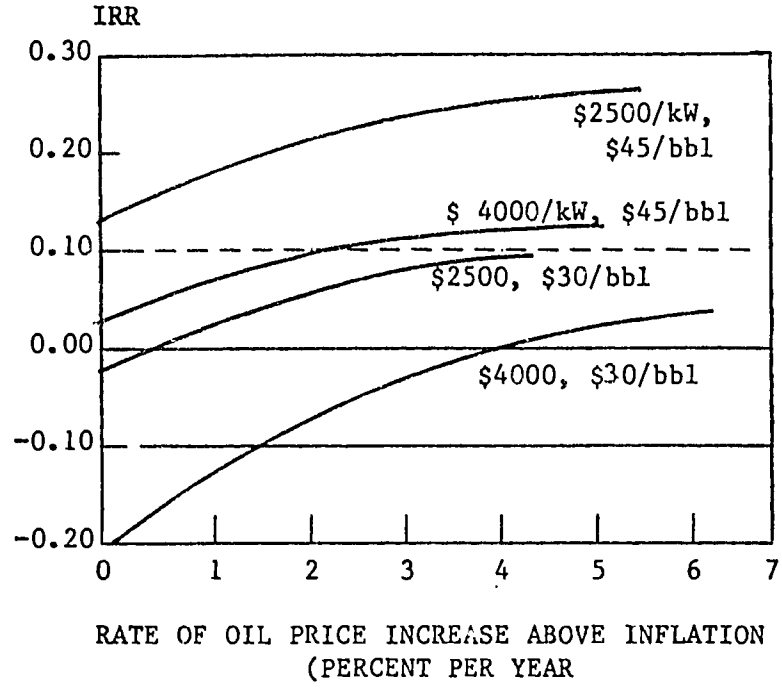

Figure 2. Internal Rate of Return (IRR) as a Function of the Rate of Increase in Oil Prices and Capital Cost, for the SIPH System.

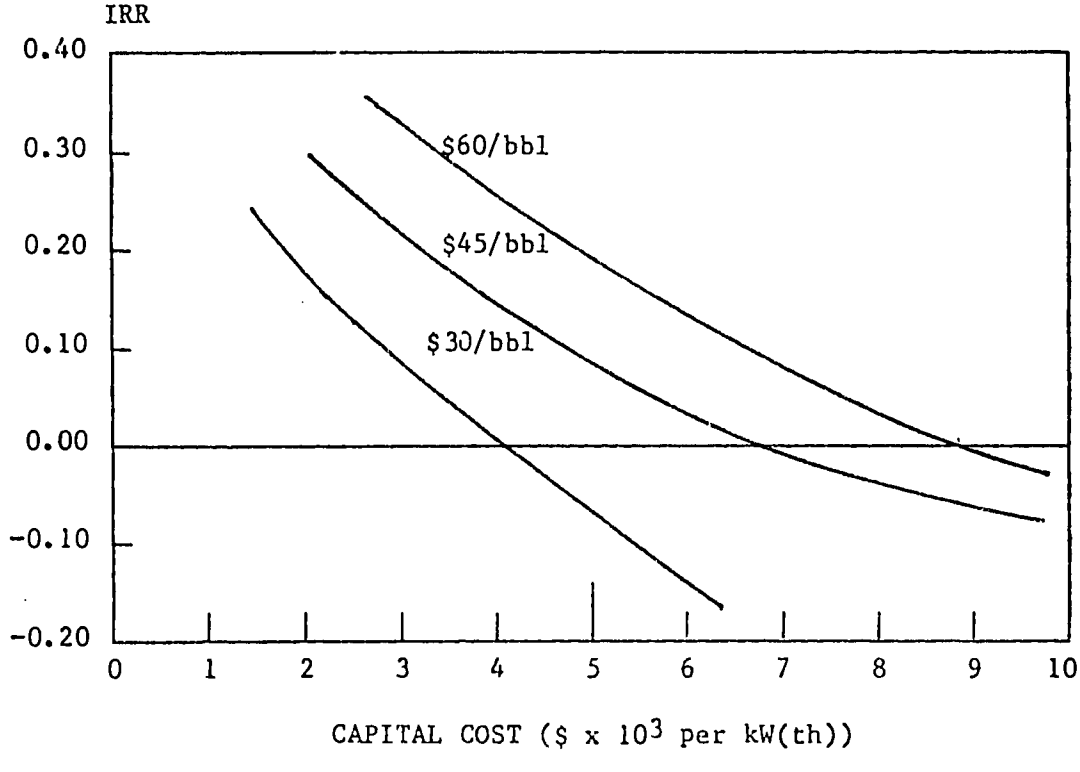

Figure 3. Internal Rate of Return (IRR) as a Function of Capital Cost and Oil Prices for the SIPH System.

Table 8
Internal Rate of Return (percent/year) for the Base Case as a Function of System Capital Cost and Oil Prices

Capital Cost ($/kW)	Oil Prices ($/bbl) 30	45	60
2,500	8.5	21.6	33.1
4,000	-1.3	10.0	18.4
6,000	-12.9	1.3	8.7
8,000	-50.1	-5.4	2.6
10,000		-12.9	-2.5

5.3.2 IRR vs Investment Tax Credit

In this example (Table 9 and Figure 4), the IRR for SIPH investment is an increasing function of the investment tax credit (ITC). The presence of a 15 percent ITC for certain solar applications, including SIPH, raises the effective IRR from a negative value to a positive one at the world 1980 price of oil. In some cases, the additional availability of local and state tax credits can raise the effective ITC even further. In the case of a 40 percent ITC, which some countries or regions may wish to implement to stimulate a local solar industry and widespread solar thermal applications, the IRR would be 14 percent, contrasted with under 6 percent with no ITC present. As Figure 4 suggests, the ITC is one of the powerful incentives available to a government to favorably shift the investment environment for solar energy technology investments.

5.3.4 IRR vs Percent Equity

The debt/equity ratio for an investment in capital-intensive solar hardware will also determine the IRR (Figure 5 and Table 10). For investments with low returns, the greater the debt (i.e., lower the equity), the worse the internal rate of return. This is due to the increased interest payments on low equity investments. When the investment becomes more attractive, this

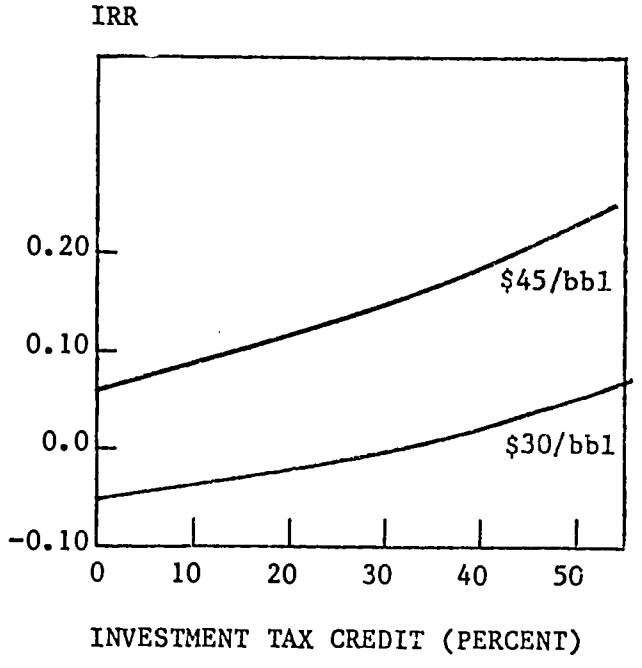

Figure 4. Internal Rate of Return (IRR) as a Function of Investment Tax Credit for the SIPH System.

situation is reversed as seen in Figure 5. Official policies regarding allowable debt/equity ratios will be one of the factors determining the extent to which an investment in solar technologies will become attractive.

5.3.5 IRR vs Debt Interest Rate

As expected, the internal rate of return will decline as the debt interest rate increases (Table 11, Figure 6). An increase in the interest rate from 11 percent per year to 20 percent per year results in a decline in the IRR from a positive to a negative value. As with certain other measures, the effective interest rate charged for debt incurred in renewable energy investments will strongly affect the internal rate of return. The use of soft loans for such technologies will clearly result in much more attractive rates of return than conventional financing, for instance.

5.3.6 IRR vs Depreciation Period

For a world oil price of $45/bbl, the Internal Rate of Return falls smoothly for depreciation periods that are different from around eight years (Figure 7). Accelerated depreciation is usually a powerful tool for creating investment incentives. However if the depreciation allowance is greater than the net cash flow after costs during the relevant years, then the taxable income is negative and no taxes are paid during the years of negative taxable income. Hence during these periods there would be increase in net cash flow after taxes.

The longer the taxable income is negative, i.e., the longer the depreciation life, the better the stream of cash flow after taxes. This is reflected in the increase in the IRR with the increase in the depreciation life up to eight years. After eight years, the taxable income becomes positive during the years where allowance is made for depreciation. After year

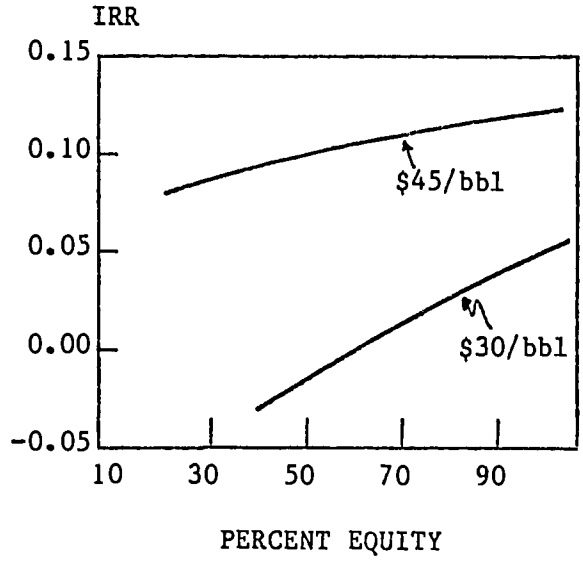

Figure 5. Internal Rate of Return (IRR) as a Function of Percent Equity, for the SIPH System.

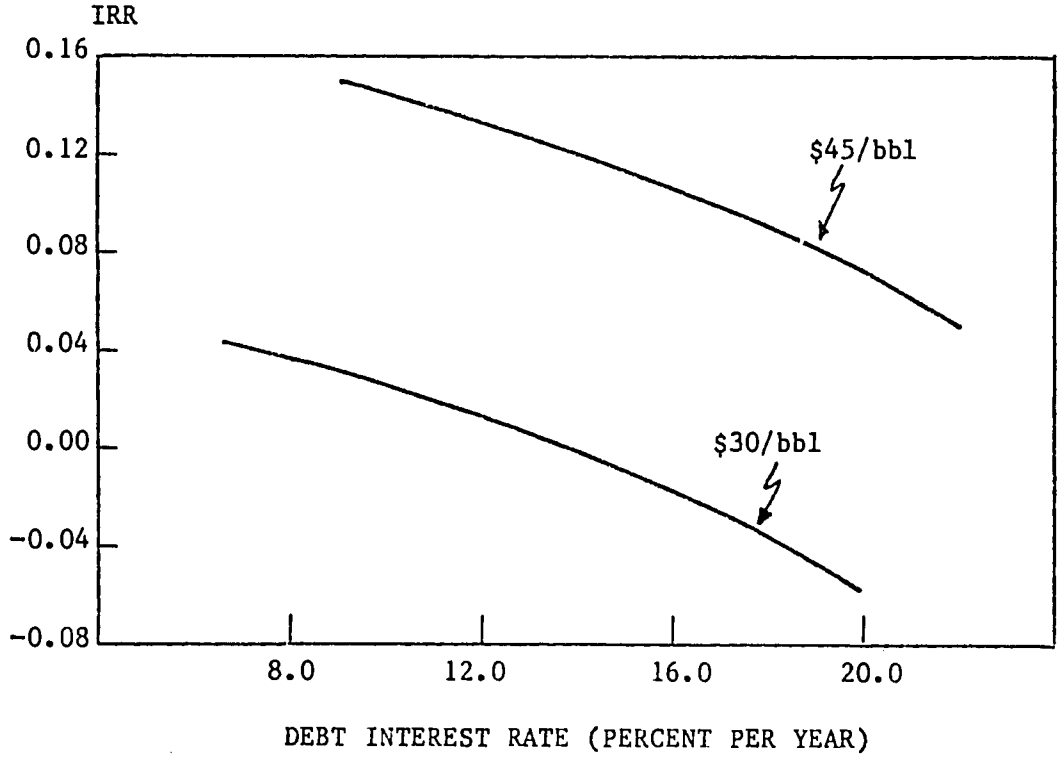

Figure 6. Internal Rate of Return (IRR) as a Function of Debt Interest Rate, for the SIPH System.

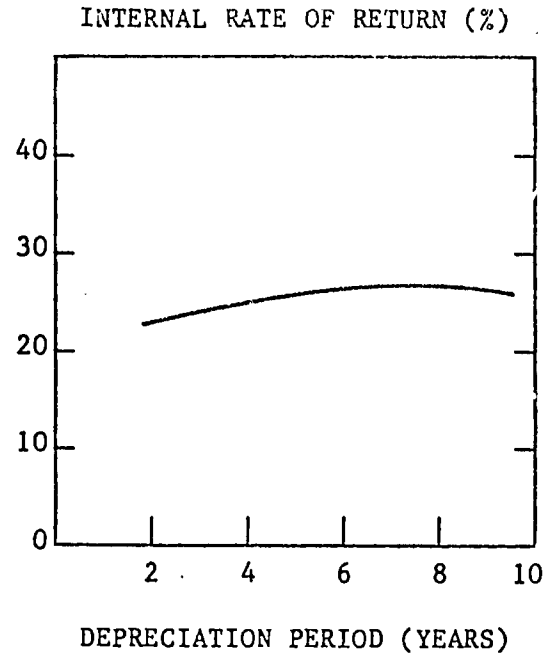

Figure 7. Internal Rate of Return as a Function of Straight Line Depreciation Period for Solar Industrial Process Heat.

Table 9
Internal Rate of Return (percent/year) as a Function of Investment Tax Credit for the Base Case

Investment Tax Credit	IRR (@ $45/bbl)	IRR (@ $30/bbl)
00	5.7	-3.8
10	7.1	-2.9
25	10.0	-1.3
40	14.4	1.1
50	19.2	3.4

Table 10
Internal Rate of Return (percent/year) as a Function of Percent Equity, for the Base Case

Percent Equity	IRR (@ $45/bbl)	IRR (@ $30/bbl)
30	8.6	-8.5
40	9.4	-4.3
50	10.0	-1.3
65	10.5	1.8
80	10.9	3.8
100	11.3	5.7

Table 11
Internal Rate of Return as a Function of Debt Interest Rate, for the Base Case

Debt Interest Rate (%/year)	IRR (@ $45/bbl)	IRR (@ $30/bbl)
11.0	13.0	2.3
13.0	11.5	0.5
15.0	10.0	-1.3
17.5	8.1	-3.6
20.0	6.3	-6.1

negative taxable income. Hence during these periods there would be increase in net cash flow after taxes.

The longer the taxable income is negative, i.e., the longer the depreciation life, the better the stream of cash flow after taxes. This is reflected in the increase in the IRR with the increase in the depreciation life up to eight years. After eight years, the taxable income becomes positive during the years where allowance is made for depreciation. After year eight, the taxable income would vary in direct proportion to the depreciation life leading to a decrease in the net cash flow after taxes with an increase in the depreciation life. This is reflected by the fall in the IRR after 8 years which is the expected behavior in most cases.

7 POLICY CONCLUSIONS

We analyzed the impact of various economic and financial incentives on investment in solar industrial process heat to displace conventional fuels.

It is clear that at current (1982) world oil prices ($30/bbl), investment in solar industrial process heat (SIPH) is marginal at best even with investment incentives and at the capital cost of $4000/kW. As better engineering reduces the capital cost, the rate of return on investment for SIPH improves to the point of being quite attractive at a capital cost of $2500/kW. If the import premium of oil is 50% making the price of oil ("shadow price") $45/bbl, which is well within the range estimated for the U.S.,[4] the investment picture changes drastically. The internal rate of return for SIPH investment at a capital cost of $2500/kW is 10% at a fuel escalation rate of 3% and is positive even if no real fuel price increase is assumed and there are no investment incentives.

Our analysis lead us to two important conclusions. Unless better engineering design leads to a drastic reduction in capital costs, SIPH would be uneconomical at the market price of oil even with reasonable investment incentives.* However if there is a premium (shadow price less market price) for imported oil and this premium is around or above 50%, SIPH investments

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*Such cost reducing innovations are being attempted in many countries. For instance, new solar energy flat-plat collectors using thin-film polymer materials are now under development at Brookhaven National Laboratory.[12] The objective of this work is to lower substantially the cost of flat-plate collectors consistent with acceptable performance and durability. These collectors currently appear capable of providing temperatures in the range of 150° to 200°F, and are therefore suitable for relatively low-temperature process heat applications or for pre-heating when higher temperatures are desired. Preliminary studies have already indicated cost advantages over fossil energy sources without any form of government subsidy. Should this cost advantage be retained through the process of commercial development, government policy on solar energy in developing countries is likely to be altered profoundly.

would be economical even without government incentives. Hence the price at which these estimations are made are very important. Conversely the government can levy a selective tax on the oil products used for industrial process heat, increase the market price to the shadow price and thereby increase the incentive for investment in SIPH.

At an international market price of $45/bbl for oil, investment in Solar Industrial Process Heat would be competitive with conventional process heat systems. The competitiveness could be improved further by structuring a scheme of investment incentives all of which result in an increase in the rate of return. Government actions could include:

- Development and diffusion of the engineering and industrial skills to design, install, and operate highly efficient and reliable solar IPH systems in conjunction with industrial process heat facilities.
- Introduction of investment tax credits for investments in renewable energy technologies.
- Establishment of special interest rates and conditions for loans for investments in equipment which increases energy efficiency or which makes use of indigenous renewable energy resources.
- Introduction of accelerated depreciation for renewable energy technology investments. In this example there was an optimum depreciation life of 8 years.

We have not discussed other factors which could make an investment in such facilities even more attractive than a simple economic analysis would suggest. For instance, if most or all of the SIPH equipment were eventually fabricated within the country using the systems, this would imply an increased indigenous technical, engineering, and industrial capability which could be applied to other aspects of industrial development. For oil-importing LDC's, the shadow price of oil, which will remain higher than the world market price for some time, should also encourage governments to provide suitable incentives for the use of indigenous renewable sources of energy.

For oil-exporting LDC's, renewable energy technologies will free for export oil and gas which would otherwise be required for domestic use.

The opportunities for the use of renewable energy technologies such as SIPH will require imaginative, aggressive, and sustained technical and policy measures to ensure that these opportunities are realized on a scale which could contribute to meeting an important portion of energy needs in LDC's around the world.

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APPENDIX A

A.1 THE FINANCIAL MODEL

A.1.1 VARIABLES (Endogenous - calculated by the model)

Capital Recovery Factor	CRF
Amount of Debt	TD
Annual Debt Service	M
Annual Interest Payment	IP
Annual Principal Payment	PP
Annual Property Tax and Insurance Payment	PT
**Annual Operation and Maintenance Costs	OM
Initial Investment Allowed for Depreciation	B
Salvage Value of Capital Cost	L
Annual Depreciation Allowance	DE
Deductible Costs	DCOST
**Gross Annual Cast Flow	GCF
Taxable Income	TI
Taxes Paid	TAX
Investment Returned as Tax Credit	ITC
Total Costs	TCOST
Net Cash Flow After Taxes, Principal Payment, Costs	NCF
Debt as Fraction of Capital Costs	D

A.1.2 PARAMETERS (Exogenous - given to the model)

Project Life	N
Capital Cost	CC
Depreciation Life	DL

**First Year Values Specified

Cash Flow Escalation Rate	r_1
Fraction of Capital Cost that is Equity	e_1
Debt Interest Rate	r
Property Taxes and Insurance Escalation Rate	r_2
O & M Escalation Rate	r_3
Fraction of Capital Costs Allowed for Depreciation	d_1
Salvage Value as Fraction of Capital Cost	d_2
Corporate Income Tax Rate	t
Investment Tax Credit Rate	tc

**First Year Values Specified

A.1.3 EQUATIONS*

1. Gross Annual Cash Flow = 1st Year Cast Flow x Rate of Growth

$$GCF(k) = GCF(1) \times (1 + r_1)^{k-1}$$

2. Debt as Fraction of Capital Cost = Total less Equity

$$D = 1 - e_1$$

3. Amount of Debt = Capital Cost x Fraction of Debt

$$TD = CC \times D$$

4. Capital Recovery Factor = FUNCTION (debt interest, lifetime)

$$CRF = r/ \quad 1 - (1 + r)^{-N}$$

5. Annual Debt Service = Debt Amount x Capital Recovery Factor

$$M = TD \times CRF$$

6. Annual Interest Payment = Debt Amount x Debt Interest Rate

$$IP(k) = TD \times r$$

7. Annual Principal Payment = Annual Debt Service - Interest Payment

$$PP(k) = M - IP(k)$$

8. Annual Property Tax Payment = 1st Year Prop. Tax x Rate of Growth

$$PT(k) = PT(1) \times (1 + r_2)^{k-1}$$

*Time is given by k.

9. Annual O & M Costs = 1st Year O&M Costs x Rate of Growth

$$OM(k) = OM(1) \times (1 + r_3)^{k-1}$$

10. Initial Investment Allowed for Depreciation = Capital Costs x Fraction Allowed

$$B = CC \times d_1$$

11. Salvage Value of Capital Cost = Capital Cost x Salvage Fraction

$$L = CC \times d_2$$

12. Annual Depreciation Allowance = FUNCTION (depreciation life (I4), option)

12.1 Double Declining Balance Depreciation

$$DE(k) = 2(B-L) / DL \times (1 - 2/DL)^{k-1}$$

$$S1(k) = (B-L) \times (1 - 2/DL)^{k-1}/(DL - k + 1)$$

$$DE(k) = \begin{cases} DE(k) \text{ if } DE(k) > S1(k) \\ S1(k) \text{ if } DE(k) \leq S1(k) \end{cases}$$

12.2 Sum of Year Depreciation

$$DE(k) = 2(B-L) \times (DL - k + 1)/DL \times (DL + 1)$$

12.3 Straight Line Depreciation

$$DE(k) = (B-L) / DL$$

13. Deductible Costs = Interest Payment + Property Taxes + O&M Costs + Depreciation

$$DCOST(k) = IP(k) + PT(k) + OM(k) + DE(k)$$

14. Taxable Income = Gross Cash-Flow - Deductible Costs

TI(k) = GCF(k) - DCOST(k)

15. Taxes Paid = Taxable Income x Tax Rate

TAX (k) = TI(k) x t

16. Investment Returned as Tax Credit = Capital Cost x Tax Credit Rate

ITC = CC x tc

17. Total Costs = Interest Payment + Property Taxes + O&M Costs

TCOST(k) = IP(k) + PT(k) + OM(k)

18. Net Cash Flow After Taxes = Gross Cash Flow - Total Costs - Principal Payment - Taxes

For $k \neq 1$: NCF(k) = GCF(k) - TCOST(k) - PP(k) - TAX(k)

NCF(1) = GCF(1) - TCOST(1) - PP(1) - TAX(1) + ITC

19. Equity in Project = Capital Cost x Equity

NCF(0) = CC x e_1