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ENERGY REDUCTION ANALYSIS REPORT FOR TROPICANA SOLAR PROCESS STEAM SYSTEM

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PREPARED FOR
THE UNITED STATES
DEPARTMENT OF ENERGY
DIVISION OF SOLAR ENERGY

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SECTION 1

INTRODUCTION AND SUMMARY

SECTION 1

INTRODUCTION AND SUMMARY

A primary purpose of introducing solar energy systems into industrial process steam applications is to permit reductions in total plant requirements for conventional fossil fuels. Current projects, such as the prototype system planned for Tropicana Industries' orange juice plant at Bradenton, Florida, are intended to pave the way for more widespread solar use. To achieve this, analyses such as the one contained in this report may be further validated by data from actual plant operation when solar system installation and checkout is completed. A continuing correlation with other potential industrial applications will subsequently be possible and the knowledge thus gained effectively shared by industry personnel making plant facility decisions for future energy systems. This report presents the economic assessment data pertinent to the current Tropicana system configuration and projects the potential for energy reduction through use of additional and/or larger systems.

Principal Findings

The principal conclusions and findings resulting from this energy reduction analysis are as follows:

- Scale-up of the Tropicana solar energy system for citrus industry use will be cost effective for contributions up to 25 percent of total load at installed system costs of \$7 to \$ 20 per square foot of collector array, dependent upon fuel prices.
- Solar energy contributions to load of greater than about 25 percent require very large collector arrays plus the use of energy storage to match solar output to the load. The use of storage and increased array size progressively reduces the annual energy savings per square foot of collector.
- Regional fuel costs and insolation level differences must be considered individually in evaluating specific applications.
- Conditions for solarization of low pressure steam applications is most attractive in the southern regions of the United States.
- Moderate to heavy fuel price escalation rates above general inflation, together with legislative incentives, are needed for high solar energy penetrations in the near to mid-term.

- Unless legislative incentives are passed, continued effort to reduce installed system costs per square foot of collector array to less than \$ 10 will be necessary, and costs below \$ 6 per square foot appear necessary outside Regions V and VI.
- The use of solar energy to reduce fossil fuel requirements for all U. S. low pressure process steam applications has a maximum potential in the order of 5-6 percent of present total U. S. energy consumption if installed system costs can be reduced sufficiently. This is equivalent to between six hundred million and seven hundred twenty million barrels of oil annually.

SECTION 2

ECONOMIC MODEL

SECTION 2

ECONOMIC MODEL

2.1 APPROACH

The energy savings actually achieved by the application of solar energy to produce industrial low-pressure steam will be most heavily affected by system economics. At zero system cost the maximum potential would be realized since all the low-pressure steam-consuming industries would see economic attractiveness. At the other extreme, there is some solar system price at which there will be no penetration of solar process heat and thus no industry energy savings. Potential savings will be presented as a function of normalized break-even installed system cost ($\$/\text{ft}^2$ of solar collector area) for various rates of fuel escalation above inflation. The potential energy savings of the conceptual design applied to a portion of the Tropicana plant will be extrapolated to:

1. Tropicana plant-wide energy savings
2. Citrus juice industry-wide energy savings
3. Energy savings of low-pressure steam-consuming industries.

2.2 MODEL PARAMETERS

Many of the simple investment evaluation techniques, such as payback time or simple return, suffer from two major drawbacks:

1. Life of the investment is not considered
2. Uneven costs and/or benefit streams cannot be handled.

The second item is of critical importance to alternate energy systems since virtually any economic scenario projects rising energy prices and therefore a steadily increasing benefit stream from an alternate energy system. For this reason, considerable effort has been made to stress "life cycle costing" for energy systems.

True life cycle cost analysis must necessarily consider the timing of costs and benefits as well as the magnitude. A method employed in previous General Electric solar and wind energy programs is to compare Levelized Annual Benefits (LAB), representing system energy savings, with the Levelized Annual Cost (LAC), the levelized dollar amount required during each year of the life of the system to:

1. Pay operating and maintenance expenses
2. Pay taxes, including corporate (where applicable)
3. Pay prorated interest on debt
4. Pay prorated return to stockholders
5. Build a capital fund that will allow for periodic component replacement or overhaul and retirement of debt.

For cost evaluation and comparison of systems for future implementation it is appropriate to express the Levelized Annual Cost (LAC) referenced to a particular base year, e. g., 1977. The result is the levelized annual cost in constant (base year) dollars given by:

$$\text{LAC (constant \$)} = \frac{\text{CRF}'}{\text{CRF}} \cdot \text{FCR} \cdot V + A_{\text{OM}} \quad (1)$$

where V is the capital cost or "value" of the solar system and A_{OM} is the annual system operation and maintenance cost. The parameter FCR is the fixed charge rate and represents the yearly cost of ownership, expressed as a percent of the capital cost, V. These costs consist of interest, principal and dividend payments on capital, taxes, and insurance. The parameter CRF is the capital recovery factor, defined as the uniform periodic payment (as a fraction of the original principal) that will fully repay a loan (including all interest) in yearly periods over the loan lifetime at a specified yearly interest rate. The interest rate used to calculate CRF is called the discount rate and represents the weighted average cost of capital. The parameter CRF' is the corresponding capital recovery factor in constant (base year) dollars.

The Levelized Annual Benefit (LAB) represents the solar system energy savings and is expressed by:

$$\text{LAB (constant \$)} = M' \cdot p_f' \cdot \text{ANNUAL ENERGY SAVINGS} \quad (2)$$

where p_f' is the fuel price in constant (base year) dollars per energy unit and M' is a multiplier, defined as the levelized value of an escalating cost stream, which accounts for the rate of fuel escalation above inflation over the lifetime of the system.

The break-even system cost occurs when the Levelized Annual Benefits (LAB) and the Levelized Annual Cost (LAC) are equal.

For the analyses to follow, a general inflation rate of 5 percent and a solar system life of 20 years will be assumed. In addition, the effect of fuel price escalation will be treated parametrically for rates of zero to 15 percent above inflation.

Values of the multiplier M' for different relative fuel price escalation rates are given in Table 2-1.

Table 2-1. Energy Cost Multiplier

Rate of Fuel Price Escalation Above Inflation (%)	Multiplier M'
0	1.0
5	1.61069
10	2.73000
15	4.81789

SECTION 3

TROPICANA PLANT AND CITRUS JUICE INDUSTRY ENERGY SAVINGS POTENTIAL

SECTION 3

TROPICANA PLANT AND CITRUS JUICE INDUSTRY ENERGY SAVINGS POTENTIAL

In the economic analysis of the solar production of process steam for Tropicana Products, Inc. Fixed Charge Rates (FCR) of 0.19 and 0.36 were calculated for discount rates of 10 and 20 percent, respectively, which represent the approximate bounds of values for industry. Values for the fixed charge rates were based on: straight-line depreciation, 1.5 percent insurance plus local taxes, and a corporate income tax rate of 47 percent (corresponding to Moody's 1977 Industrial Manual listing for Tropicana Products, Inc.)

Tropicana uses natural gas for their primary fossil source but has been forced to rely heavily on oil backup due to extensive curtailments in the last few years. At present, oil is the most expensive fuel and, therefore, the obvious candidate for solar displacement. Tropicana reports a 1977 cost for oil of \$2.23/MBtu which is representative of the region (Florida).

The solar energy conceptual design for the Tropicana application utilizes 10,000 square feet of active solar collector area. Levelized annual savings and costs for this Tropicana process steam application expressed as a function of installed system cost, annual energy savings, and energy price escalation rate were determined for discount rates of 10 percent (Figure 3-1) and 20 percent (Figure 3-2).

Annual operating and maintenance costs were assumed to be absorbed in the day-to-day operation of the Tropicana plant and all system components were assumed to have a 20-year life; i.e., replacement costs were neglected. A plant steam production efficiency of 70 percent was employed in the model.

As an example using Figure 3-1, a 10 percent energy price escalation rate with annual energy savings of 280,000 Btu/ft² would require an installed system cost of \$19.5/ft² to

Figure 3-1. System Economic Viability for Tropicana Process Steam (10% Discount Rate)

Figure 3-2. System Economic Viability for Tropicana Process Steam (20% Discount Rate)

break-even with a 10 percent discount rate. Similarly, Figure 3-2 indicates a break-even cost of \$ 7/ft² under the same conditions with a 20 percent discount rate.

In order to properly extrapolate the Tropicana application energy savings to plant-wide savings, the effect of collector area on annual energy savings must be taken into account. Normalized annual energy savings as a function of collector area presented in Figure 3-3 were generated from the results of Figure 3-4 using the 1.0 gal/ft² thermal storage curve as a basis. These results were generated for the 5 continuous pasteurizer units in the solar application at Tropicana which require an annual process steam energy load of 1.2×10^{11} Btu. It should be pointed out that the results of Figure 3-3 require rearrangement to a "percent of load" basis for energy savings scale-up to plant-wide and industry-wide values. This result is shown in Table 3-1.

Since the annual process steam energy load for the Tropicana plant is 8×10^{11} Btu, scale-up to plant-wide energy savings in Btu per year is accomplished by a linear extrapolation factor of 6.67 over the collector area range of Figure 3-3.

Figure 3-3. Effect of Collector Area on Energy Savings

Figure 3-4. Solar Energy Supplied to Generate Steam
at 135 psig to the Pasteurizer

Table 3-1. Energy Savings versus Percent of Load

Annual Energy Savings (kBtu/ft ² -yr)	Percent of Load
290.7	17.0
269.7	31.5
256.0	44.9
246.2	57.5
232.9	68.0
219.3	76.9
204.3	83.6
188.4	88.1

Once the plant-wide energy savings potential is established, industry savings can be estimated. This will be considerably less difficult for the orange juice processing industry than for other steam consuming sectors due to the heavy concentration of the industry. Over 92 percent of the plants and over 99 percent of orange juice production is in the state of Florida. Thus, there is little industry variation in such factors as solar insolation, fossil fuel supply, and energy prices.

The annual process steam energy load for the citrus juice industry is 2.2×10^{12} Btu yielding an energy savings scale-up factor of 2.75 over that of the Tropicana plant.

The potential energy savings for the Tropicana plant and the citrus juice industry as a function of break-even installed system cost and fuel price escalation are graphically illustrated in Figure 3-5. The break-even cost results from equating LAC (equation (1)) and LAB (equation (2)) and then solving for the system cost V. The system costs of Figure 3-5 are presented in terms of constant 1977 dollars per square foot of collector area.

Note that with no fuel price escalation above inflation a very low ($3-4 \$ / \text{ft}^2$) system cost is necessary for substantial penetration. The 5 percent fuel price escalation curve improves the picture but still indicates a system cost of less than \$8 per square foot for penetration. The 10 and 15 percent escalation curves indicate systems costs of less than \$10 and \$20 per square foot, respectively, are necessary for substantial penetration.

Figure 3-5. Potential Energy Savings as a Function of Installed System Cost for Tropicana Plant and Citrus Industry

SECTION 4

INDUSTRIAL LOW-PRESSURE STEAM ENERGY SAVINGS POTENTIAL

SECTION 4

INDUSTRIAL LOW-PRESSURE STEAM ENERGY SAVINGS POTENTIAL

The assessment of the overall potential for industrial solar process steam must necessarily involve many factors peculiar to each region and industry evaluated. Regional factors include fossil fuel supply characteristics, energy prices, and solar insolation among others. Industry specifics affecting solar process steam include, obviously, present process requirements. Further process changes and energy source changes must also be considered as well as energy intensity of the final product.

Determination of the energy savings potential of the low-pressure steam-consuming industries requires disaggregation of the overall industry by solar insolation region and fuel price (oil is assumed as best candidate for solar augmentation). The United States has been divided into six major climatic (solar) regions (Ref. 1) as shown in Figure 4-1. Tropicana and the citrus juice industry are contained in Region V. The average fuel (oil price and annual energy load for each region is given in Table 4-1.

Figure 4-1. Solar Regions of the United States

Table 4-1. Regional Fuel Price and Energy Load

Region	Oil Price (\$ /MBtu)	Annual Energy Load (10^{15} Btu/yr)
I	2.11	1.34
II	2.06	1.78
III	1.95	1.06
IV	2.05	1.84
V	2.23	0.91
VI	2.54	0.07

The average fuel (oil) price for each region was obtained from Reference 1 and escalated to 1977 dollars using the citrus juice industry (Region V) oil price (\$ 2.23/MBtu) as a scale base. The figures for regional annual energy loads were also obtained from information provided in Reference 1 and scaled up to match the total low-pressure steam demand of 7×10^{15} Btu per year.

For each fuel price, solar region and economic scenario, there is a normalized system cost (\$/ft² collector area) at which solar process heat annualized costs become equal to fuel costs and energy savings initiate. Lower system costs increase savings as more collector area becomes economic. Savings versus system price can thus be computed for each characteristic plant grouping. It is clear that plants in good solar regions (IV, V and VI) will first reach economic viability as system price is reduced, while energy users in poorer solar regions (I and II) will be the last.

A working nomograph was then generated for the low-pressure steam-consuming industries using Table 3-1 and the levelized annual cost and savings expression given in Section 2.2. This nomograph is depicted in Figure 4-2. The energy savings in kBtu/(ft²-yr) for each region as graphically illustrated in Figure 4-2 were obtained using Table 3-1 which represents Region V, and then scaled for the other regions from information provided in Reference 1. This nomograph was then used to predict the potential energy savings for the entire low-pressure steam industry.

Figure 4-2. Working Nomograph - Potential Low Pressure Steam-Consuming Industry Load Savings

To illustrate the function of the nomograph in Figure 4-2, the zero relative fuel price escalation will serve as an example. For a given installed system cost, the percent of load savings in each region may be determined using the fuel prices from Table 4-1. For example, in Region V an installed system cost of \$ 5 per square foot divided by the average oil price in Region V (\$ 2.23/MBtu) equals 2.24 MBtu per square foot which corresponds to 22 percent of load savings at zero differential fuel price escalation. Similarly for Region VI, a \$ 5 per square foot system cost (oil price = \$ 2.54/MBtu) corresponds to 85 percent of load savings. All other regions provide zero load savings at \$ 5 per square foot. The total energy savings from all the regions at \$ 5 per square foot system cost is then summed using the regional load values from Table 4-1. That is, 22 percent of 0.91×10^{15} Btu per year plus 85 percent of 0.07×10^{15} Btu per year yields 0.26×10^{15} Btu per year energy savings potential. Results for installed system costs ranging from \$ 1.5 to \$ 6 per square foot are tabulated in Table 4-2 for the zero differential fuel price escalation scenario.

Table 4-2. Low-Pressure Steam Savings - Zero Differential Fuel Price Escalation

Installed System Cost (\$/ft ²) =	1.5	2	3	4	5	6	Percent of Load Savings
Region I	90%	57%	0	0	0	0	
II		90%	30%	0	0	0	
III			61%	0	0	0	
IV			81%	29%	0	0	
V			90%	72%	22%	0	
VI				90%	85%	67%	
Annual Energy Savings (10 ¹⁵ Btu/yr)	6.30	5.86	4.40	1.25	0.26	0.05	

This procedure was repeated for the 5, 10 and 15 percent relative fuel price escalation scenarios and graphically illustrated in Figure 4-3 where the potential energy savings of solar process heat in low pressure steam-consuming industries is plotted as a function of the break-even system cost in constant 1977 dollars per square foot of collector area. Note that with zero relative fuel price escalation a very low (less than \$4/ft²) system cost is necessary for

Figure 4-3. Potential Energy Savings in Low Pressure Steam Applications

substantial penetration. The 5 percent scenario improves the picture somewhat but still indicates a system cost of less than \$ 6 per square foot for penetration. The rather high escalation scenarios of 10 and 15 percent indicate system costs of less than \$10 and \$ 20 per square foot, respectively, are necessary for substantial penetration. While these prices are more attractive, the relative escalation rates of 10 and 15 percent are considered severe to extreme by today's forecasters.

Future System Cost Projections Based on Economics of Scale

The costs associated with the solar process steam system shown in the last section would be economically prohibitive, probably even in the event of a complete loss of fossil fuel sources in the citrus industry. Fortunately, it is not anticipated that the costs shown reflect the true situation for future systems. Three factors are involved that would result in much lower solar energy costs. First, the system used for the cost estimates is the first such system ever built and as such reflects the large costs associated with development; that is, with learning how to build the system at minimum cost. Second, the collector price is that associated with first generation solar collectors. Currently, the cost is somewhat greater than \$ 20 per square feet. Estimates indicate that this price could approach \$10 per square foot when production rates increase to levels anticipated in 1980 - 1985 time period. This is an economy of scale associated with collector quantity production. Another economy of scale is associated with increasing the size of the solar process steam system. The system that has been designed for Tropicana is for a single pasteurizer and glycol concentrator. To provide the same fraction of process steam for the entire plant would require a system approximately 6.7 times the size of the present demonstration. The cost of increasing the size of the system is not directly proportional to its size, but rather to the size ratio raised to some fractional power.

Previous experience with scaling equipment costs (Ref. 2) indicates that the size ratio raised to the 0.6 power provides a reasonable approximation for present economic extrapolations. The resulting extrapolated values include labor as well as material cost increases. Cost scaling data developed from catalog component costs are shown in Table 4-3 and tend to support the 0.6 power theory.

Table 4-3. Cost Scaling Factors Associated with Size Increases for Several Components (Includes: Labor, Material, Shipping, Install., O/H, Profit)

Category	Size Factor	Cost Ratio (Size Factor)	Exponent (X)
1. Heat Exchanger	5	1.7	0.35
	10	3.1	0.5
2. Piping (CU Insulated)	5	6.7	1.18
	10		
3. Centrifugal Pump (+ Install.)	5	1.75	0.35
	10	2.0	0.30
4. Pressurized Tank (+ Install.)	5	3.3	0.75
	10	5.0	0.70
5. Steel Structure	5	5	1.0
	10	10	1.0
6. Collectors	5	?	
	10	?	
7. Electrical Cable	5	3.1	0.70
8. Expansion Tanks	5	2.3	0.50
	10	4.1	0.60

(1) "Building Construction Cost File - 1974 Eastern Edition," Construction Publishing Company, Inc.

Reference to the breakdown of system costs shown in Table 4-4 would enable one to further refine the scaling calculation, but we have not carried the calculations into this degree of detail at this time. Using the scaling exponent of 0.6 we computed the curves shown in Figure 4-4 and present the cost per 10^6 Btu versus system size. About half of the fuel cost is solar, the other half being the fossil contribution. The data point at unity size represents the baseline Tropicana system and represents the current system cost estimate minus the development costs and without instrumentation for data processing or for display.

Table 4-4. Cost Data for Baseline Tropicana System
(Includes, Labor, Overhead and Materials)

Category	Cost	Percent Total
Mechanical Components and Insulation	\$130,000	32
Structural Collector Array Support	50,000	13
Electrical Components	15,000	4
360 Collectors	200,000	50
Controls	5,000	1
Total System	\$400,000	100%

The four curves shown represent constant collector costs at \$20, \$15, \$10, and \$5 per square foot. It is clear that for large systems, the decrease in solar energy costs could qualify the system to compete economically with fossil fuels in many areas of the country. The introduction of legislature incentives that would permit a tax deduction based on the amount of fossil fuel saved via solar would lower any one of the four curves by an appreciable amount, thus making the large systems still more attractive, Note lower curve in Figure 4-4. This, in fact, would be equivalent to placing solar and fossil energy on the same basis since at the present time the cost of fossil fuel is a legitimate tax deduction which results in an after tax saving of half the fuel cost.

- BASELINE DATA POINT IS BASED ON TROPICANA INDUSTRIES SOLAR PROCESS STEAM SYSTEM COSTS

- \$20/FT² COLLECTOR
- \$20/FT² INSTALLATION
- \$40/FT² TOTAL (10,000 FT²)

- CALCULATIONS ARE BASED ON STANDARD DOE PLAN "B"

Figure 4-4. The Effects of Scaling Economics on Fuel Price for Four Solar Collector Costs

SECTION 5

REFERENCES

SECTION 5
REFERENCES

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