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SERI/TR-431-580

April 1980

Economics of Selected WECS Dispersed Applications

Stella Krawiec

SERI

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Operated for the
U.S. Department of Energy
under Contract No. EG-77-C-01-4042

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Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price:
Microfiche $3.00
Printed Copy $4.50

SERI/TR-431-580
UC CATEGORY: UC-60

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STELLA KRAWIEC

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PREFACE

This technical report, prepared as a part of Task No. 6720.40, presents an economic analysis for distributed wind energy conversion systems. Included are the breakeven analysis and life-cycle cost models, and a calculation of the cost of electricity generated by selected wind systems in residential and agricultural applications. The breakeven capital cost of wind systems competing with conventional power sources in dispersed applications is also estimated.

The author wishes to express appreciation for the technical assistance offered by W. Benson of Midwest Research Institute and by several staff members of the Solar Energy Research Institute: S. Christmas and B. Witholder, Economics Analysis Branch, and R. Hewett, Quality Assurance and Standards Branch.

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SUMMARY AND CONCLUSIONS

An economic analysis for distributed Wind Energy Conversion Systems (WECS) has been conducted for the Department of Energy (DOE) as part of the Solar Commercial Readiness Assessment task at the Solar Energy Research Institute (SERI).

The objective of this paper is to analyze:

- The cost of electricity generated by selected wind energy systems in residential and agricultural applications,
- The breakeven cost of wind systems able to compete economically with conventional power sources in dispersed applications, and
- The impact of major economic factors on the cost performance index.

Two major measures of economics used are breakeven period and levelized cost of electricity (life-cycle cost).

The cost performance index was calculated for a dispersed application of a commercially available 10 kW wind turbine generator. All-electric homes consuming 15,000 kWh annually or more have been selected for analysis. The agricultural application is represented by a commercial poultry and egg farm demanding over 92,000 kWh annually.

The economics of WECS in dispersed applications is strongly site-dependent for the following reasons: the performance of the systems is a function of wind resources; today's fuel prices and electric rates, which determine immediate cost and savings, vary across the nation; and load profiles even in the same application are affected by seasonal changes that vary across the nation.

The impact of major economic factors on the cost performance index is based on analysis of the following parameters: installed cost of WECS; cost of electricity; evaluation rates for the price of electricity; capacity factor as a function of system performance and wind velocity; and wind energy output utilization fraction as a function of user's load profile and WTG output curve.

The study concludes with several observations. The present price of small (1-40 kW) commercially available WECS ranges from $1,000-$6,000/kWh (1979$). Some existing systems are competitive in limited segments of any given market. In areas representing high wind resources (Alaska, Hawaii, New England) and/or high prices of conventional fuels, small scale WECS appear to be economically viable even today, particularly for applications that qualify for federal incentives contained in the National Energy Act of 1978.

Significant reductions in wind system energy costs (as compared to those required for market initiation) are required to enable these systems to compete effectively with conventional energy systems. The breakeven cost under the best market conditions, those analyzed in this paper, should not exceed $1,200/installed kW (1979$). The capital cost of the wind systems have to be reduced to the range of $600-$800/kW (1979$) for broad market applications.

The number of economically feasible applications for WECS is expected to increase markedly as the price of conventional fuels increase, and WECS prices decline, through mass production, to about $600 to $800 per installed kilowatt at a rated wind speed of 18 mph.

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SECTION 1.0

INTRODUCTION

Although interest in wind energy is increasing, wind energy conversion systems (WECS) have yet to achieve widespread commercialization. Commercialization is a multistage process in which a system is developed to a point of economic and technical viability. Technical progress and the resolution of numerous economic and noneconomic issues are required before widespread acceptance of WECS.

System cost and economics have a major influence on the commercial readiness of a system. In addition to a system's technical reliability, the cost of energy produced by WECS is a key factor upon which prospective users will base their purchase decisions. The principal role of the technology development activity is to reduce the cost of energy to the point at which the wind system is competitive with conventional systems.

This paper analyzes the breakeven/market relationship and the different economic values of wind systems for the various markets. A set of conditions is developed that is necessary to enable these systems to become economically competitive.

1.1 ECONOMIC ANALYSIS ASSUMPTIONS

The following assumptions were used in the residential and agricultural distributive WECS economic analysis:

- For both applications, the analysis is based upon the technical and economical performance of the commercially available Model 10-3-IND 10 kW machine produced by Millville Wind and Solar Equipment Company. The installed cost is in the range of $1,000 to $1,100/kW.
- The WECS annual output is estimated for three of the most typical sites in the United States. The data used, which detail the percentage of time that different wind speeds occur at each site, were provided by Rocky Flats Plant.
- Two measures of economic performance are the breakeven period and the levelized cost of electricity.
- For residences, the economic analysis is based on an all-electric home requiring 15,000 kWh of electricity annually.
- The agricultural application is represented by a commercial poultry and egg farm demanding over 92,000 kWh annually.
- Wind systems, in both applications, are competing against electric power generated by the local utility.
- The wind energy used by the homeowner or farmer is valued at the average retail price of electricity (for 10 selected states) up to the point where wind generation reaches required application load. Electricity generated in excess of the required home or farm loads is sold back to the utility at the fuel replacement value (average fuel cost for selected states to generate net kWh of electricity).

SECTION 2.0

METHODOLOGY

The economic evaluation of wind energy systems is approached through analysis of breakeven period and life-cycle cost. Both models are parametric, since costs and savings are a function of many variables that differ by geographic region as well as by end user. Models can be used for performing sensitivity analyses.

Although the cost and savings elements associated with purchasing, owning, and operating a wind machine are the same for both analyses, equations describing model processing are different. Determination of amounts and timing of cash flows is performed differently for each model.

2.1 BREAKEVEN ANALYSIS MODEL

The breakeven costs and savings accumulated over a certain period of time are computed by a quantitative model. The breakeven period is achieved when the present value of cumulative savings equals the present value of cumulative costs. Figures 2-1, 2-2 and 2-3 show the overall model logic for residential and agricultural applications, respectively. The parametric values used in the model are provided in Table 2-1.

2.1.1 Model Processing

The model processing is based on computations of annual costs and savings for each operating year. The equations used in computing the breakeven period for distributive wind systems applications are given. Definitions of the symbols and parametric values used in the equations are provided in Tables 2-1 and 2-2.

2.1.1.1 Equations Used in Computing Present Value (PV) of Costs for Year "n" on a Year-by-Year Basis

- Down payment, D:

$$D = d \times C \; .$$

- Present value of annual mortgage payment, PV(M):

$$PV(M) = (1 - d)\, C \, \frac{i\,(1 + i)^n}{(1 + i)^n - 1} \times \frac{1}{(1 + k)^n} \; .$$

- Present value of annual mortgage interest tax reduction, PV(T):

$$PV(T) = \left[(1 - d)C \left(\frac{(1 + i)^n - (1 + i)^{(n - 1)}}{(1 + i)^n - 1} \right) \frac{i}{(1 + k)^n} \right] \times f \; .$$

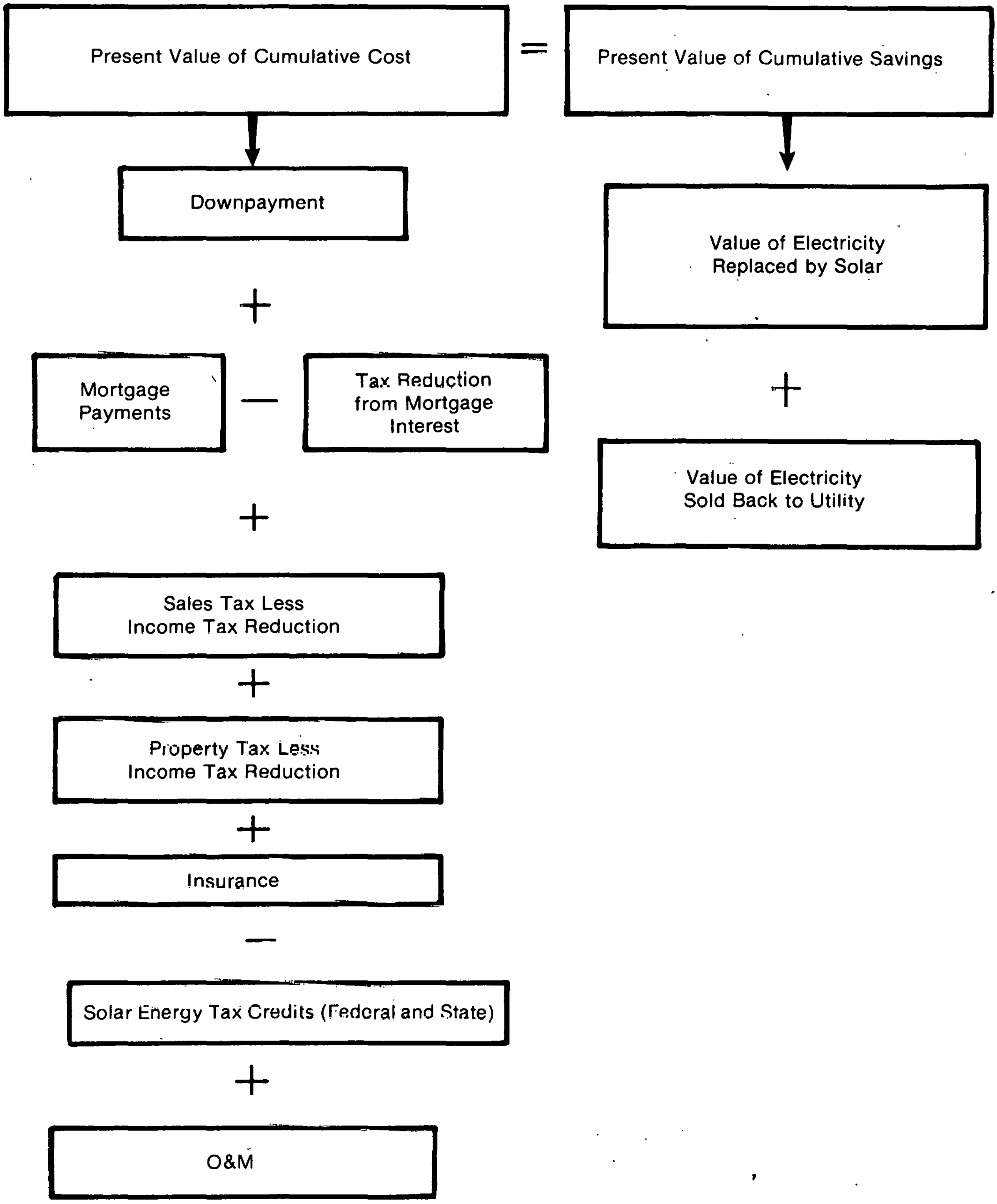


Figure 2-1. Breakeven Period Model Flow Diagram for Residential Sector Application

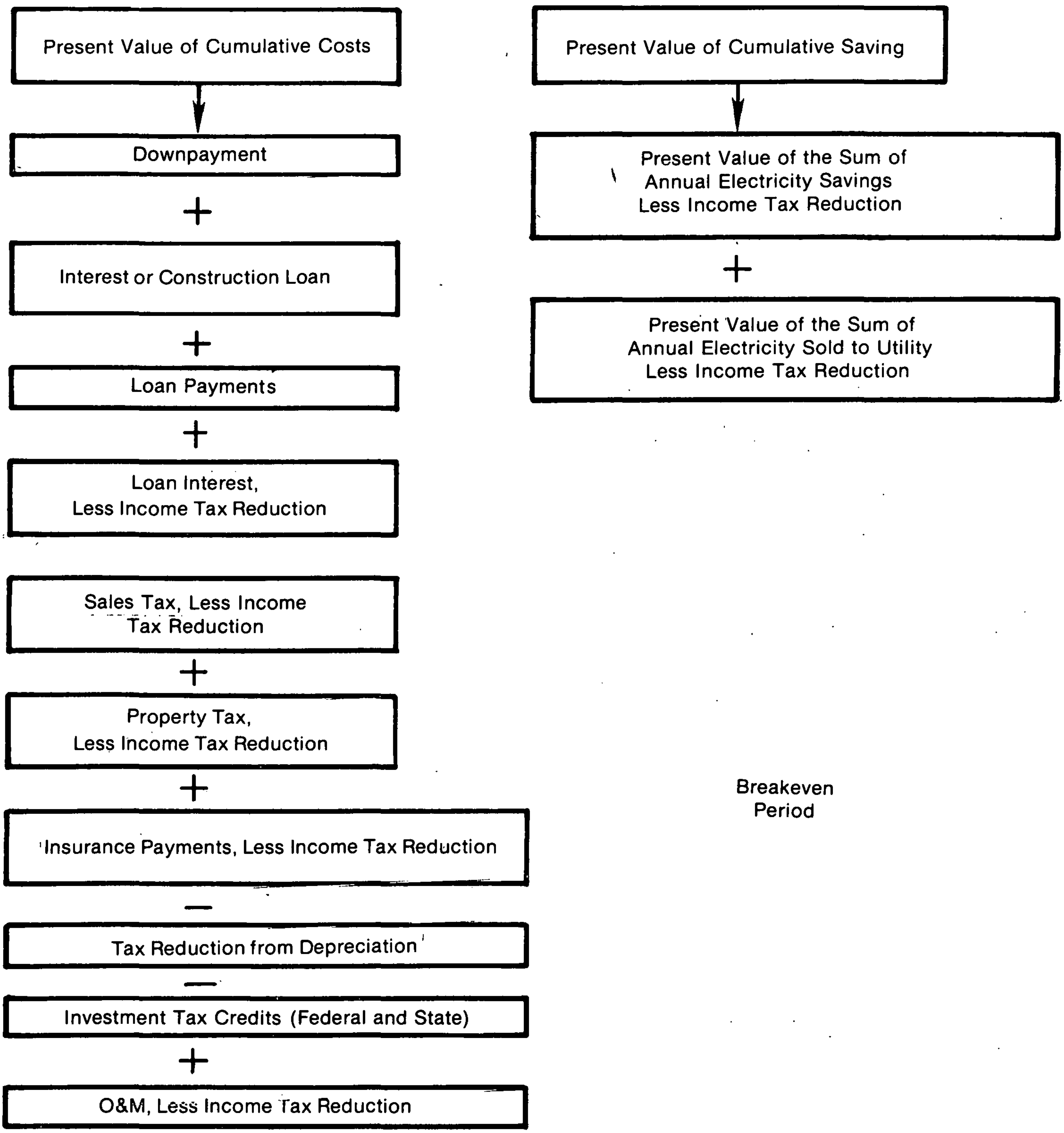
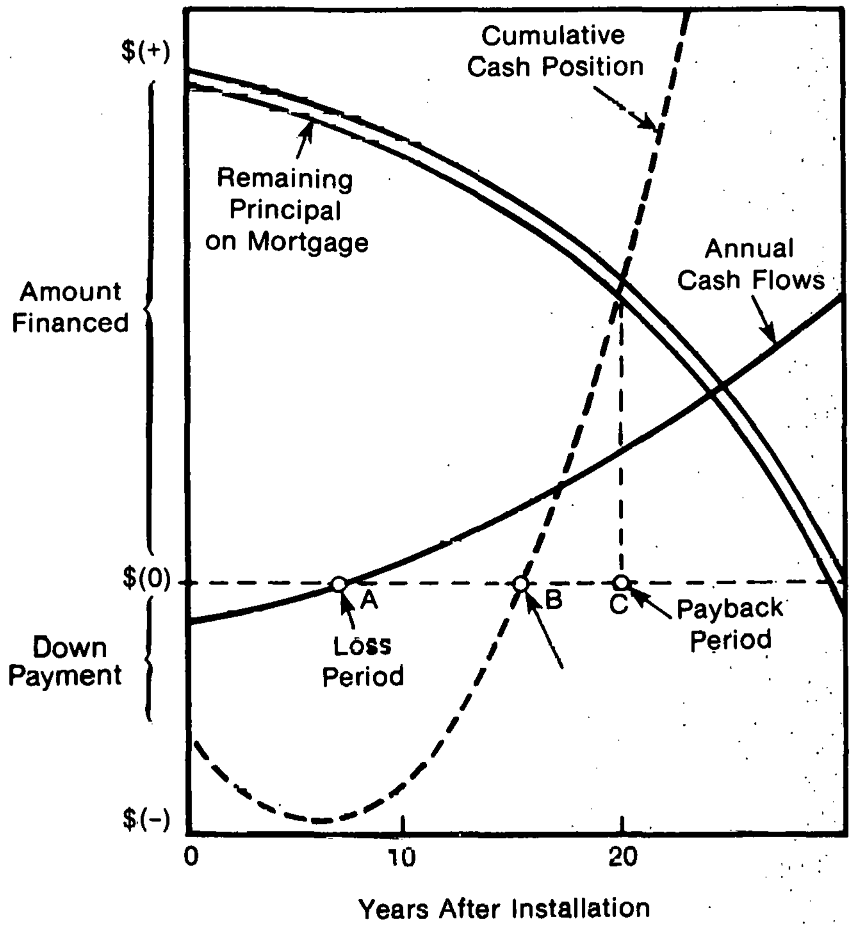


Figure 2-2. Breakeven Period Model Flow Diagram for Agricultural Sector Application



Source: Economic Incentives to Wind Systems Commercialization, Booz, Allen & Hamilton, Inc., Bethesda, MD. 1978.

Figure 2-3. Cash Flow Diagram

Table 2-1. ECONOMIC ANALYSIS PARAMETERS

Parameter Number	Parameter Description	Parameter Value: Base Case: Residential	Parameter Value: Base Case: Agricultural	Parameter Value: Alternative Cases
1	Total cost of system ($)	9,362	10,100	2,000 4,000 7,000 10,000 13,000
2	Hardware cost of system ($)	7,623	8,360	1,200 2,800 5,600 8,200 10,660
3	WECS installation cost ($)	1,739	1,740	800 1,200 1,400 1,800 2,340
4	Down payment (fraction of total system cost)	0.20	0.20	0.20 for each case
5	Mortgage period (yr)	20	20	20 for each case
6	Annual interest rate	0.11	0.10	0.11 for residential; 0.10 for agricultural
7	State sales tax rate	0.04	0.04	0.04 for each case
8	System owners marginal federal tax rate	0.25	0.25	0.25 for each case
9	Annual energy demand (kWh)	15,000	92,224	15,000 for residential; 92,224 for agricultural
10	Utilization factor of wind energy output (fraction)	0.80	0.80	0.80 and 0.60 for each case
11	General inflation rate	0.06	0.06	0.06 0.06 0.06 0.06 0.06
12	Fuel cost inflation rate	0.08	0.08	0.08, 0.10, and 0.12 for each case
13	Price of electricity ($/kWh)	0.043	0.045	0.043 for residential; 0.045 for agricultural
14	Discount rate	0	0	
15	Federal tax credit ($)	2,072	2,020	The National Energy Act (1978)
16	State tax credit ($)	0	0	
17	Annual insurance premium (% of total system cost)	0.03	0.03	0.03 for each case
18	Annual O&M cost (fraction of total system cost)	0.01	0.01	0.01 for each case
19	Wind system annual output (kWh)	11,200	14,350	Residential-- for each case: 6,000 11,200 17,900 Agricultural-- for each case: 8,000 14,350 22,000
20	Sellback ratio	0.20	0.20	0.20 and 0.40 for each case
21	Sellback price $/kWh	0.021	0.021	0.021 for each case
22	Depreciation indicator (0 = no, 1 = yes)	0	1	0 for residential; 1 for agricultural
23	Property tax rate (fraction of assessed value)	0	0	No property tax
24	Lifetime of system (yr)	25	25	25 years for each case

Table 2-2. SYMBOLS USED IN THE MODEL

D	Down payment ($)
d	Down payment as a fraction of total system cost
C	System-installed cost ($)
M	Annual mortgage payment ($)
N	Mortgage period (yr)
T	Annual mortgage interest tax reduction ($)
i	Interest rate
n	Year for which calculation is being made
k	Discount rate
f	System owner's marginal federal tax rate
S	Net effective sales tax on initial capital cost ($)
σ	State sales tax rate
P	Annual property tax ($)
p	Property tax rate
A	Assessed value of insured system ($)
h	Insurance rate
I	Annual insurance premium ($)
g	General inflation rate
g_E	Electricity inflation rate
g_F	Fuel cost inflation rate
F_f	Federal investment tax credit ($)
t_f	Federal tax credit rate
F_s	State investment tax credit
t_s	State tax credit rate
O&M	Operating and maintenance cost ($)
j	O&M cost as a fraction of system cost
u	System lifetime
r	Tax life of the system (yr)
Q_t	Wind system annual output (kWh)
Q	Annual energy needs of the homeowner or farmer (kWh/yr)
Q_u	Wind energy used by system owner (kWh)
E_u	Value of electricity replaced by wind energy ($)
Q_s	Wind energy sold back to the utility (kWh)
E_s	Value of electricity sold back to the utility ($)
q_E	Price of energy to the end user ($/kWh)
q_F	Price at which system output sold to local utility ($/kWh)
Z	Annual depreciation expense

- Net effective sales tax on initial capital cost (owing to sales tax deduction on income tax), S:

$$S = (1 - f) \times C \times s \quad .$$

- Present value of effective property tax expense (adjusted for federal income tax effects), PV(P):

$$PV(P) = \left[\frac{p \times A\ (1 + g)^n}{(1 + k)^n}\right](1 - f) \quad .$$

- Present value of annual insurance payment expense, PV(I):
  - Residential

$$PV(I) = \frac{h \times C\ (1 + g)^n}{(1 + k)^n}$$

  - Agricultural

$$PV(I) = \frac{h \times C\ (1 + g)^n}{(1 + k)^n}(1 - f) \quad .$$

- Federal investment tax credit, F_f:

$$F_f = C \times t_f$$

  - Residential

    Tax credit of 30% on first $2,000 of investment in solar system.

    Tax credit of 20% on next $8,000 investment.

    Maximum tax credit of $2,200.

  - Agricultural

    20% of investment in solar system.

- State investment tax credit, F_s:

$$F_s = C \times t_s \quad .$$

- Present value of annual O&M cost, increasing at rate g and discounted at rate k, PV(O&M):
  - Residential

$$PV(O\&M) = \frac{j \times C \times (1 + g)^n}{(1 + k)^n}$$

  - Agricultural

$$PV(O\&M) = \frac{j \times C\ (1 + g)^n}{(1 + k)^n}(1 - f) \quad .$$

- Present value of annual depreciation expense (adjusted for federal income tax effects) assuming sum-of-the-year-digits (SOYD) depreciation, PV(Z):
  - Agricultural only

$$PV(Z) = (1 - f)\ C\ \frac{2\ (u + 1 - n)}{u\ (u + 1)} \left[\frac{1}{1 + k}\right]^n .$$

2.1.1.2 Equations Used in Computing Present Value (PV) of Savings for Year "n" on a Year-by-Year Basis:

- Present value of electricity replaced by wind energy (annually) increasing at electricity escalation rate, $PV(E_u)$:

$$PV(E_u) = Q_u \times q_E \left[\frac{1 + g_E}{1 + k}\right]^n .$$

- Present value of the electricity sold back to the utility (annually) increasing at fuel cost escalation rate, $PV(E_S)$:

$$PV(E_S) = Q_S \times q_F \left[\frac{1 + g_F}{1 + k}\right]^n .$$

2.2 LIFE-CYCLE COST MODEL

The technique of life-cycle cost analysis considers total relevant costs over the life of a system. A very important step is the determination of the amount and time of positive and negative cash flows associated with wind systems over the system's life-time. Life-cycle costs are computed with a present value. In the present value model, all costs and savings are forecasted after the period of analysis (equal to life of system) and then discounted to an equivalent single cost today.

2.2.1 Model Processing

2.2.1.1 Present Value Life-Cycle Cost, PV(LCC):

Residential

$$PV(LCC) = \begin{cases} + \text{Down Payment} \\ + \text{PV Mortgage} \\ + \text{PV O\&M} \\ + \text{PV Insurance} \\ - \text{PV Tax Effects} \end{cases}$$

where

$$PV\ (\text{Tax Effects}) = \text{Tax Rate} \times (\text{PV Interest} + \text{Sales Tax} + \text{PV Property Tax}) + \text{Investment Tax Credit.}$$

Agricultural

$$PV(LCC) = \frac{1}{1 - \text{Tax Rate}} \left\{ \begin{array}{l} + \text{ Down Payment} \\ + \text{ PV Mortgage} \\ + \text{ PV O\&M} \\ + \text{ PV Insurance} \\ - \text{ PV Tax Effects} \end{array} \right.$$

where

$$PV\ (\text{Tax Effects}) = \text{Tax Rate} \times (\text{PV Interest} + \text{PV Depreciation} + \text{Sales Tax} + \text{PV Property Tax} + \text{PV O\&M} + \text{PV Insurance}) + \text{Investment Tax Credit.}$$

Given these Present Value Life-Cycle Costs PV(LCC), the Annual Levelized Costs (ALC) can be found as follows:

$$\text{ALC (in nominal dollars)} = PV(LCC) \times \frac{k\ (1 + k)^u}{(1 + k)^u - 1}$$

$$\text{ALC (in constant dollars)} = PV(LCC) \times \frac{w\ (1 + w)^u}{(1 + w)^u - 1}$$

where

$$w = \frac{k - g}{1 + g}$$

2.2.1.2 Present Value of Life-Cycle Savings PV(LCS)

$$PV(LCS) = \left\{ \begin{array}{l} + \text{ PV of electricity replaced by wind energy} \\ + \text{ PV of electricity sold back to the utility} \end{array} \right.$$

Annual Levelized Savings, ALS, is the same as ALC.

2.2.2 Equations Used in Computing Life-Cycle Cost

- Downpayment, D:

$$D = d \times C\ .$$

- Present value of mortgage, PV(M):

$$PV(M) = (1 - d)\ C \left[\frac{i\ (1 + i)^N}{(1 + i)^N - 1} \times \frac{(1 + k)^N - 1}{k\ (1 + k)^N} \right] .$$

- Present value of mortgage interest, PV(T):

$$PV(T) = \left[\frac{\dfrac{i\ (1 + i)^N}{(1 + i)^N - 1}}{\dfrac{k\ (1 + k)^N}{(1 + k)^N - 1}} - \frac{\dfrac{(1 + a)^N - 1}{a}}{(1 + k)\ \dfrac{(1 + i)^N - 1}{i}} \right] (1 - d)\ C \quad .$$

where

$$a = \frac{i - k}{1 + k}$$

- Present value of operating and maintenance cost, PV(O&M):

$$PV(O\&M) = \frac{(1 + w)^u - 1}{w\ (1 + w)^u} \times j \times C \quad .$$

where u = lifetime of the system

$$w = \frac{\text{discount rate - general inflation rate}}{1 + \text{general inflation rate}} = \frac{k - g}{1 + g}$$

- Sales tax on initial capital cost (first year of operation is charged in full)

$$S = C \times s \quad .$$

- Present value of property tax, PV(P):

$$PV(P) = \frac{(1 + w)^u - 1}{w\ (1 + w)^u} \times p \times A \quad .$$

- Present value of insurance payments, PV(I):

$$PV(I) = \frac{(1 + w)^u - 1}{w\ (1 + w)^u} \cdot h \cdot C \quad .$$

- Federal investment tax credit, F_f:

$$F_f = \frac{C \times t_F}{(1 + k)^n}$$

Residential

- Tax credit of 30% on first $2,000 of investment.
- Tax credit of 20% on next $8,000 of investment.
- Maximum tax credit of $2,200.

Agricultural

- 20% of investment in solar system.

- Present value of depreciation expenses, PV(Z), (SOYD method) Agricultural only

$$PV(Z) = C \times \frac{2\left[r - \frac{(1+k)^r - 1}{k\,(1+k)^r}\right]}{r\,(r+1)\,k} .$$

2.2.3 Equations Used in Computing Life-Cycle Savings

- Present value of electricity replaced by wind energy, $PV(E_u)$:

$$PV(E_u) = Q_u \times q_E \; \frac{(1+v)^u - 1}{v\,(1+v)^u}$$

where:

$$v = \frac{k - g_E}{1 + g_E} .$$

- Present value of electricity sold back to the utility, $PV(E_S)$:

$$PV(E_S) = Q_S \times q_F \; \frac{(1+v)^u - 1}{v\,(1+v)^u} .$$

SECTION 3.0

ECONOMIC ANALYSES

3.1 RESIDENTIAL APPLICATIONS

3.1.1 Base Case

The analysis is based on the Millville Model 10-3-IND 10 kW wind machine (installed on a 40-ft tower) and an all-electric home with an annual electricity requirement of 15,000 kWh. Figure 3-1 portrays the load profiles for a single family house located in four different sites. Such homes represent significant markets in the United States. A comparison between electric and gas installations in tract homes indicates an increasing trend toward the former. The actual value of a WECS system to a particular owner is a function of:

- The prevailing annual mean wind speed and general weather conditions;
- The cost and performance characteristics of the wind machine;
- The financial parameters affecting purchase and operations, such as the method and amount of financing, (interest rate, loan term, insurance rate, property tax), and tax credits; and
- The size and daily pattern of the electrical load served and the correlations between output curve and load profile curve.

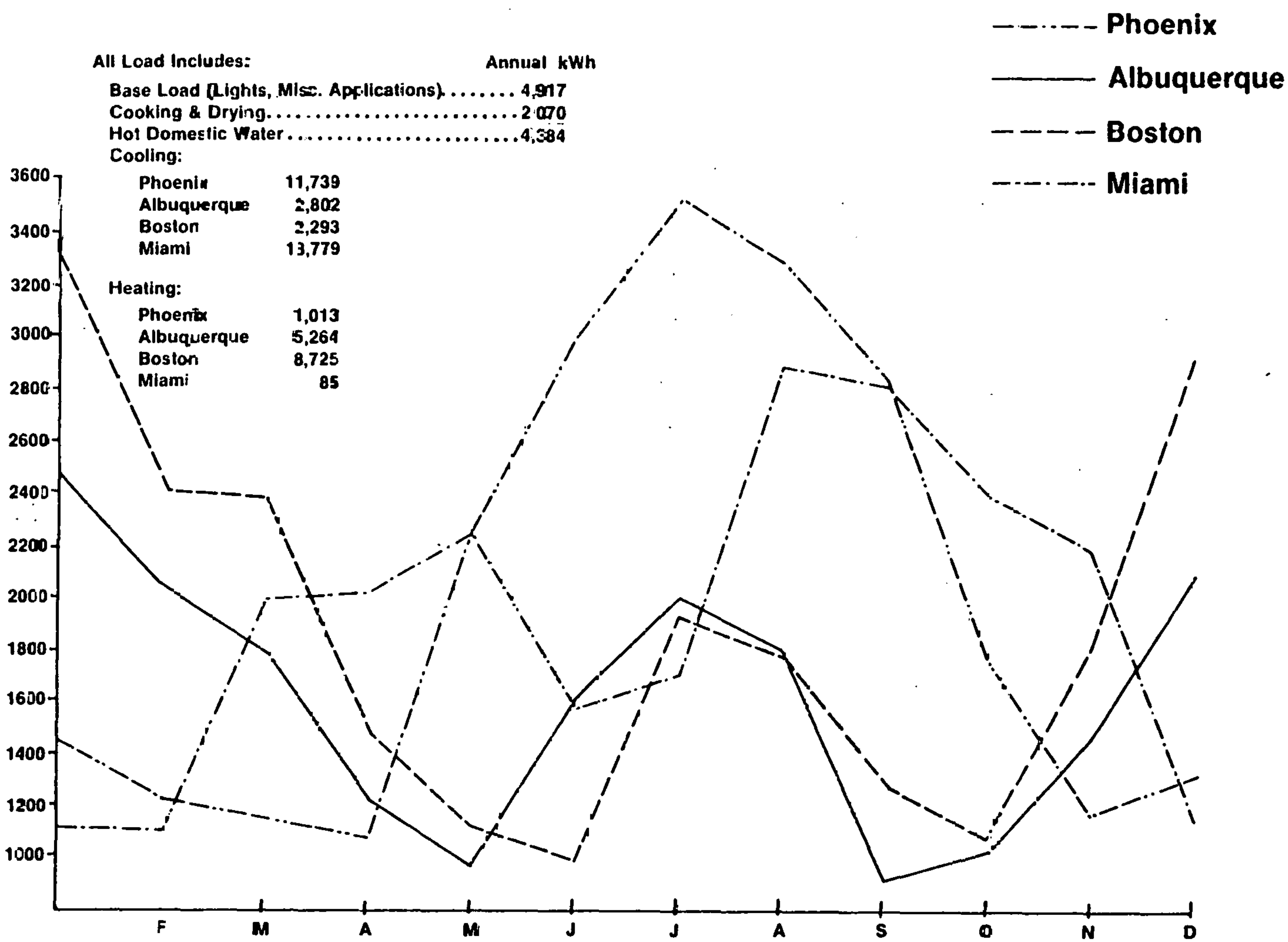
All these factors may significantly change the economics of applied wind machines. Table 3-1, a variation on the base case, shows the impact of WECS utilization factor and wind resource on breakeven period and levelized cost of electricity at three different sites. Figure 3-2 characterizes system output for the Millville Model 10-3-IND wind machine as a function of wind speed. As shown, the levelized cost of electricity for the moderate wind site (5 m/s) and 80% of utilization factor equals $0.099 kWh in nominal dollars. The corresponding breakeven period is 20 years.

Wind turbine generators located in a high wind site (6 m/s) may achieve about three times higher output compared to the output at a low wind site (4 m/s). The levelized cost of electricity decreases substantially from $0.195 kWh to $0.058/kWh.

3.1.2 Sensitivity Analysis

Many uncertainties exist regarding the capital cost of wind systems and the economic environment influencing the competition of wind systems and conventional energy technologies. The cost performance index is based on parametric analysis:

- Installed cost of WECS varies from $200 to $1,300 per installed kW;
- Cost of electricity ranges from $0.02/kWh to $0.08/kWh;



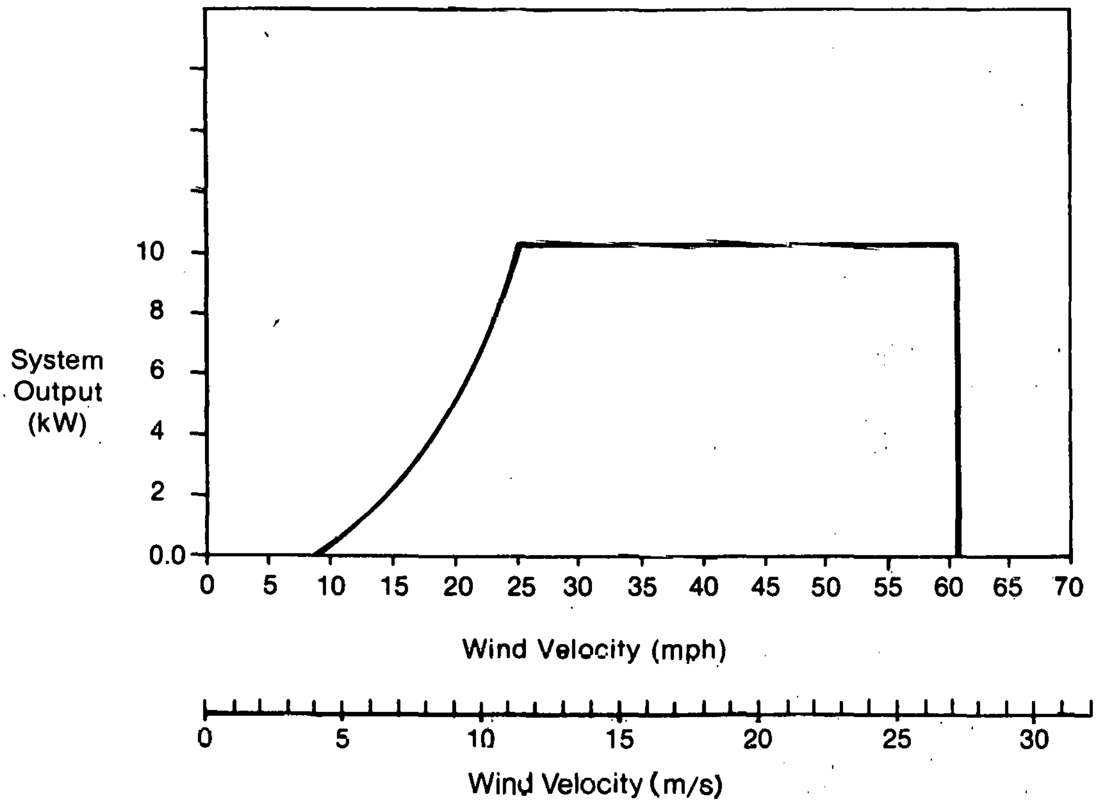
Source: General Electric, Space Division

Figure 3-1. Single Family All-Electric Home Load Profiles

Table 3-1. BREAKEVEN PERIOD AND COST OF ELECTRICITY FOR SELECTED SITES AND ENERGY UTILIZATION FRACTIONS FOR RESIDENTIAL APPLICATION

Average Wind Speed m/s at 40 ft Tower	WECS Annual Output (kWh)	Capacity Factor	Output Utilization		Sellback at $0.021/kWh		Breakeven Period (Years)	Levelized Cost of Electricity (Life-Cycle Cost) (¢/kWh)	
			Fraction	(kWh)	Fraction	(kWh)		Inflated$ [a]	Constant$ [a]
4	6000	0.068	0.8	4800	0.2	1200	39	19.5	11.4
			0.6	3600	0.4	2400	40	24.5	13.8
5	11,200	0.128	0.8	8960	0.2	2240	20	9.9	5.6
			0.6	6720	0.4	4480	25	11.7	6.6
6	17,900	0.204	0.8	14,320	0.2	3580	11	5.8	3.3
			0.6	10,740	0.4	7160	13	6.2	3.5

[a]Inflated (market) dollars include an inflation factor, whereas constant dollars are net of inflation. Either expression may be used as long as costs to be calculated are expressed in corresponding terms.



Source: A Guide to Commercially Available Wind Machines, Wind Systems Program, Rockwell International, 1978.

Figure 3-2. System Output for the Millville Model 10-3-IND Wind Machine as a Function of Wind Speed

- Escalation rates for the price of electricity changes from 8% to 12% including general inflation rate;
- Capacity factor, as a function of system performance and wind velocity, ranges from 6.8% to 20.4%.
- Wind energy output utilization fraction as a function of user's load profile and WECS output curve is altered from 80% and 60%.

Figures 3-3 through 3-6 show the sensitivity of breakeven period and system installed cost to the described factors. As shown, the capital cost of WECS and the alternative cost of electricity are two critical parameters in WECS economics. The capital cost will be reduced and wind system performance improved as technological advances are made over time. In addition, as the cost of competitive energy increases, the economics of WECS will become more attractive.

For each figure, the solution space is defined by the area below the horizontal line through eight years (assumed breakeven period) on the ordinate. To achieve the required breakeven period, if the energy utilization rate is 80% of annual WECS output, the breakeven capital cost ($/installed kW) of this system would have to be reduced to the values shown in Table 3-2.

As the WECS utilization factor increases from 0.6 to 0.8, the breakeven period decreases. Hence, wind systems are most cost effective when a close temporal correspondence exists between demand and wind availability--that is, when the overwhelming bulk of WECS output is used by the end user on site, rather than sold back to the utility.

Table 3-2. IMPACT OF ECONOMIC FACTORS ON 10 kW WTG IN RESIDENTIAL APPLICATIONS

Site Annual Output	Break-even Capital Cost $/kW at Selected Competing Cost of Electricity							
	2¢/kWh Inflated at:		4¢/kWh Inflated at:		6¢/kWh Inflated at:		8¢/kWh Inflated at:	
	8%	12%	8%	12%	8%	12%	8%	12%
4 m/s Site 6,000 kWh Annual Output	200	250	280	320	470	520	530	630
5 m/s Site 11,200 kWh Annual Output	280	350	540	630	800	910	1,000	1,130
6 m/s Site 17,900 kWh Annual Output	500	580	820	930	1,100	1,240	1,350	1,460

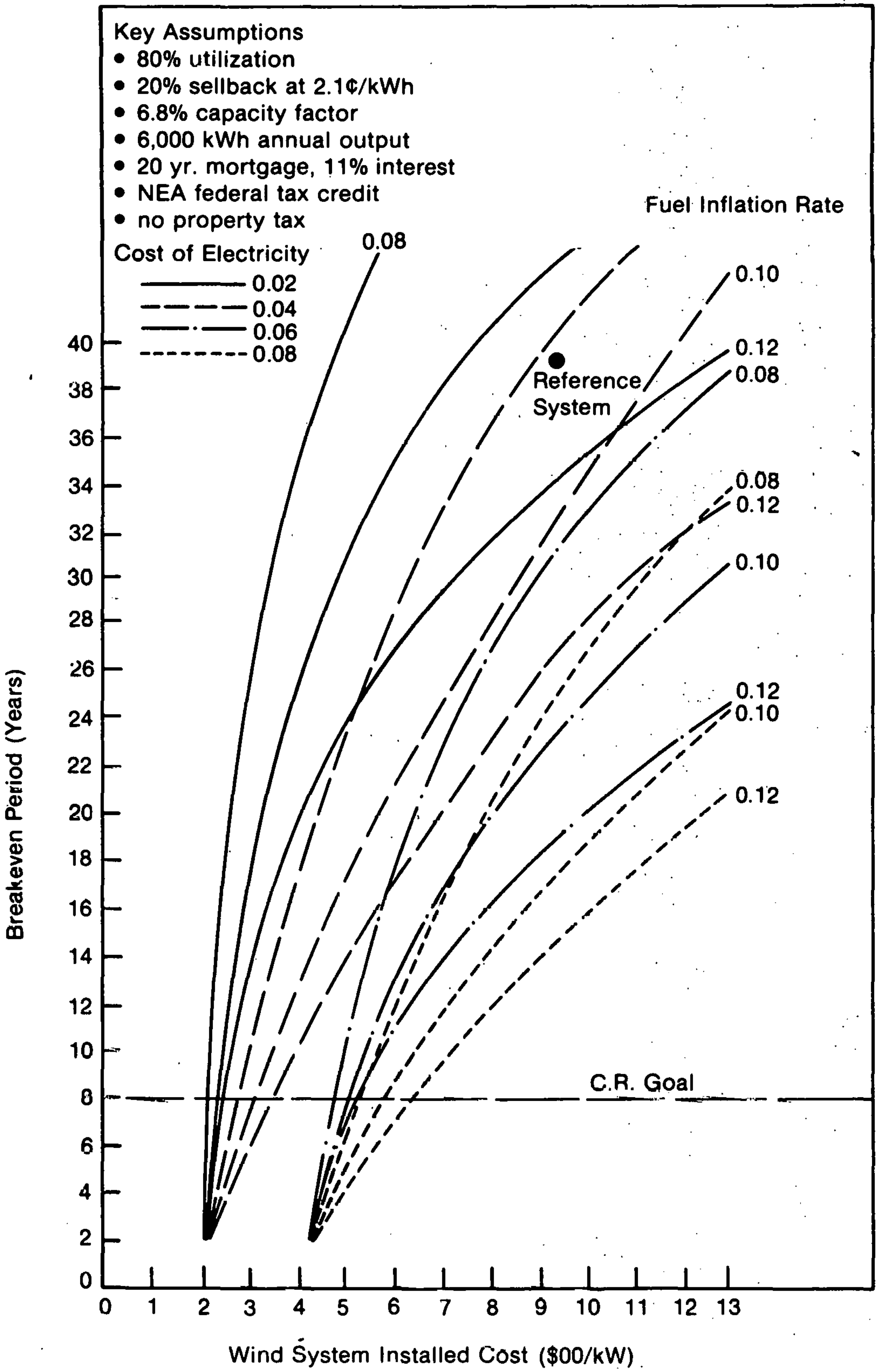


Figure 3-3. Impact of Economic Factors on 10 kW WTG in Residential Application, 4 m/s (8.9 mph) Average Wind Velocity Site (80% Utilization)

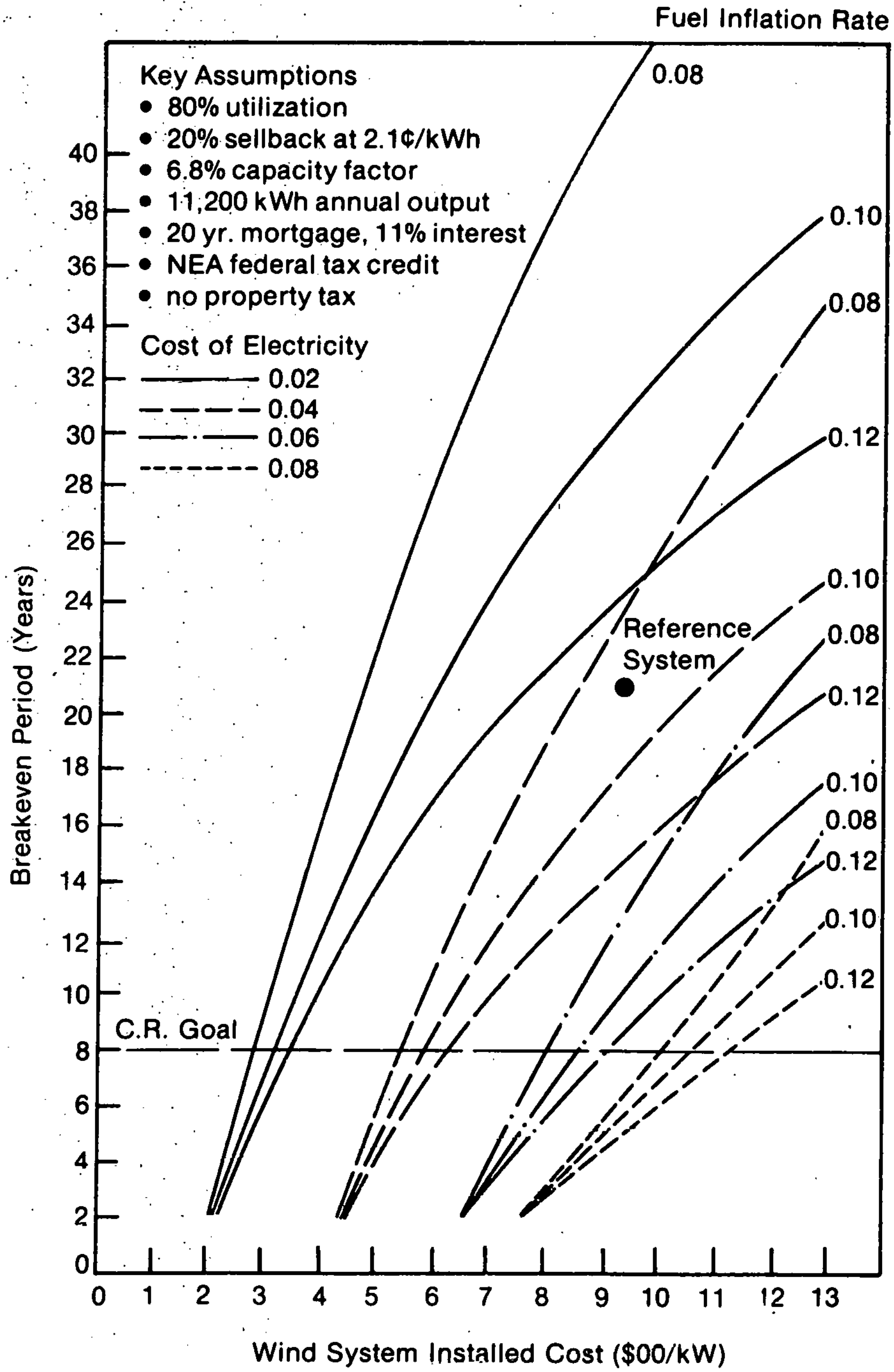


Figure 3-4. Impact of Economic Factors on 10 kW WTG in Residential Application, 5 m/s (11.2 mph) Average Wind Velocity Site (80% Utilization)

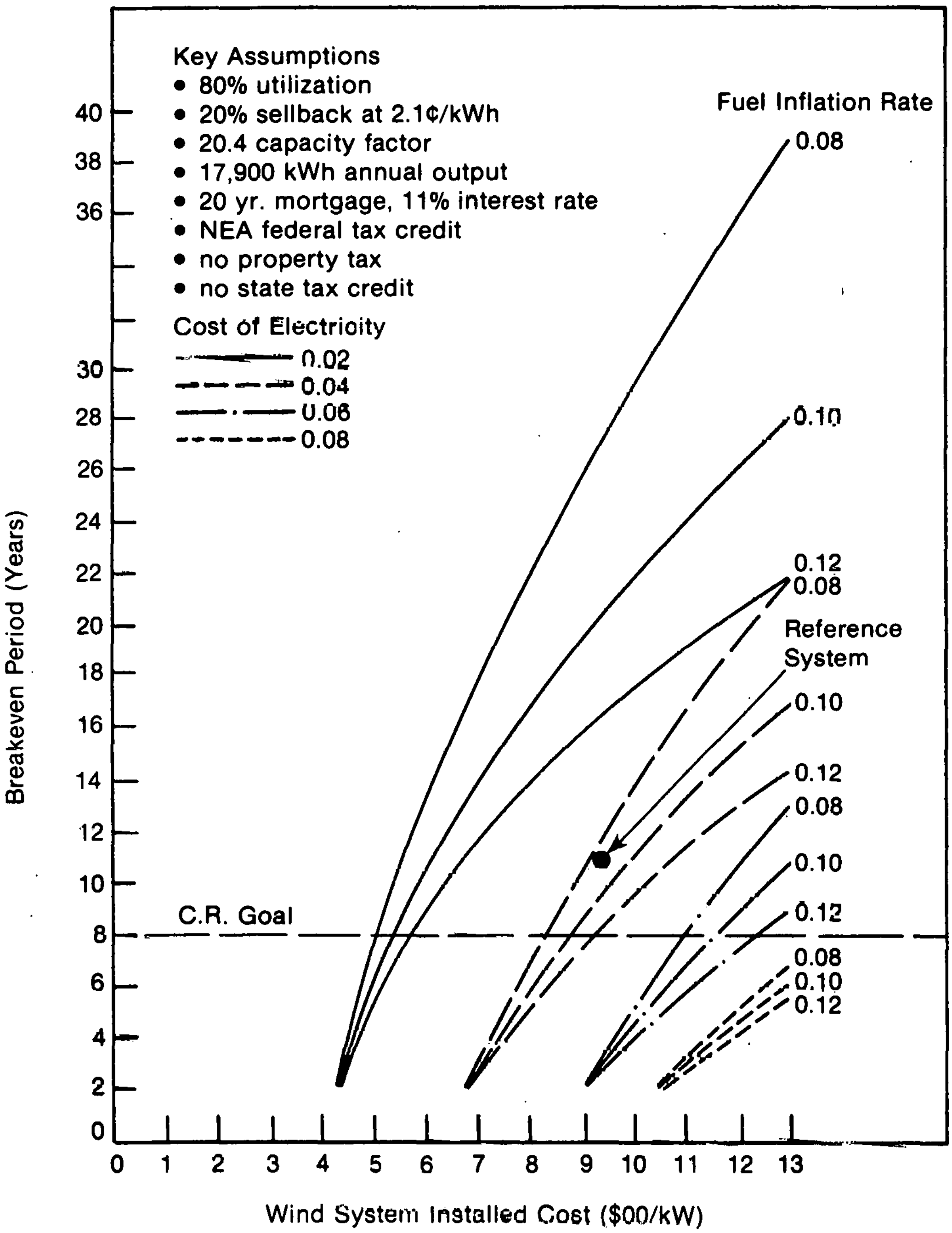


Figure 3-5. Impact of Economic Factors on 10 kW WTG in Residential Application, 6 m/s (13.4 mph) Average Wind Velocity Site (80% Utilization)

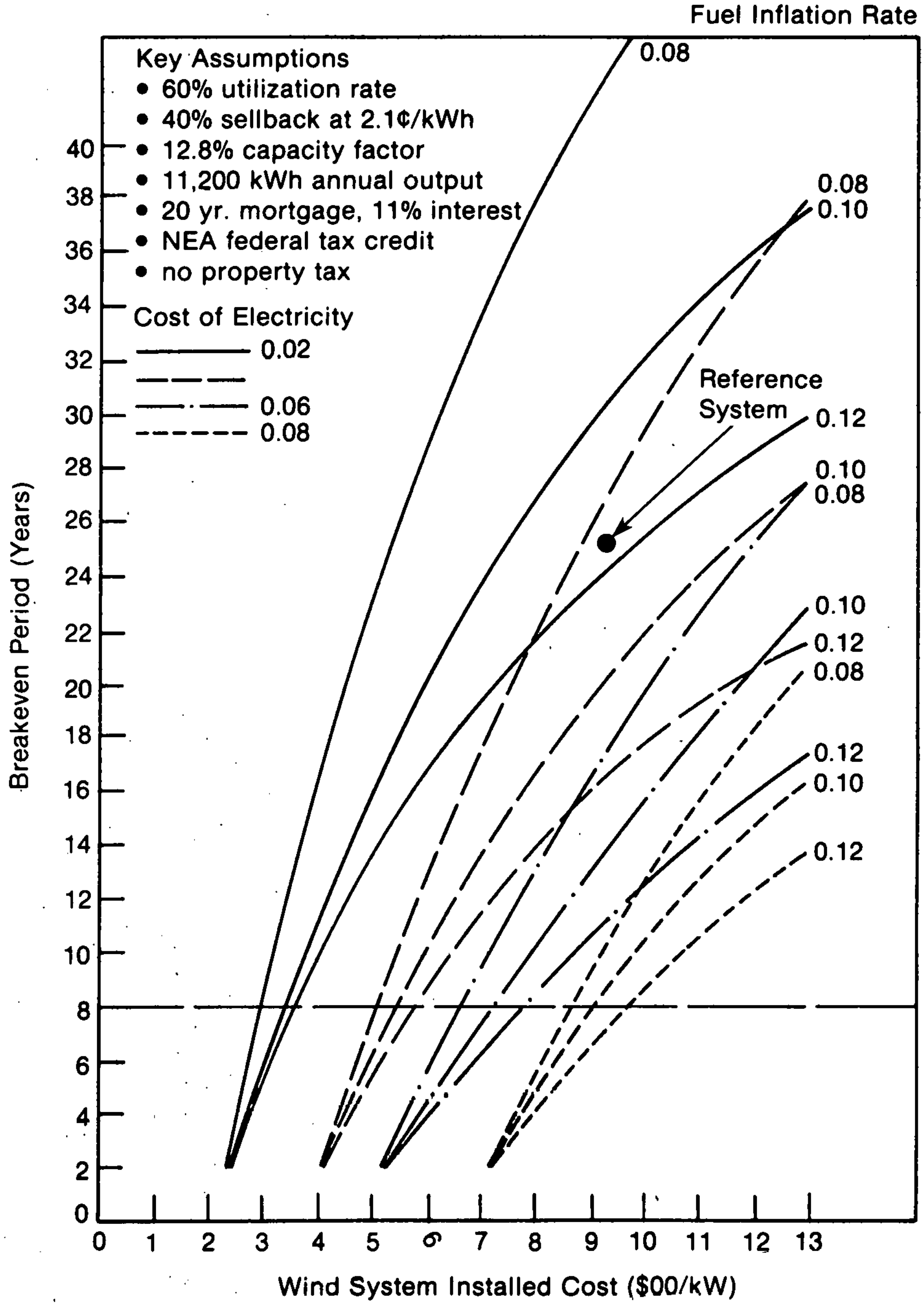


Figure 3-6. Impact of Economic Factors on 10 kW WTG in Residential Application, 5 m/s (11.2 mph) Average Wind Velocity Site (60% Utilization)

Table 3-3. BREAKEVEN PERIOD AND COST OF ELECTRICITY FOR SELECTED SITES AND UTILIZATION FRACTION (AGRICULTURAL APPLICATION)

Average Wind Speed At 60 ft High Tower	Capacity Factor	System's Output kWh/Annually	Output Utilization		Sellback (kWh)	Breakeven Period (Years)	Cost of Electricity (Life-Cycle Cost) (¢/kWh)	
			Fraction	(kWh)			Inflated$	Constant$
4 m/s	0.091	8000	0.8	6400	1600	33	15.9	9.0
			0.6	4800	3200	41	19.7	11.2
5 m/s	0.164	14,350	0.8	11,480	2870	15	8.4	4.7
			0.6	8610	5740	19	9.6	5.4
6 m/s	0.251	22,000	0.8	17,600	4400	5	5.1	2.9
			0.6	13,200	8800	7	5.2	3.1

The Millville wind machine may compete effectively under either of the following set of conditions:

I.
- Annual output 17,900 kWh,
- Utilization fraction 80%,
- Competing price of electricity $0.06/kWh escalated at 8% annually

II.
- Annual output 11,200 kWh,
- Utilization fraction 80%
- Competing price of electricity $0.08/kWh escalated at 8% annually.

Generally, wind systems already available in residential applications may be economically feasible in regions with good wind resources (6 m/s average wind velocity), particularly in locations where utility retail electric rates are either already high ($0.06/kWh) or escalating rapidly.

3.2 AGRICULTURAL APPLICATION

For agricultural applications, the economic indicators were computed for an egg farm using a Millville Model 10-3-IND 10 kW machine installed on a 60 ft tower.

The market for WECS in the agricultural sector is broad and diverse, ranging from irrigation and crop drying to home space and water heating.

Commercial poultry and egg farms appear to have characteristics best suited for WECS application (high and uniform energy requirements). Figure 3-7 portrays the load profile for a fully automated, 30,000-bird-cage farm. The following conditions exist: birds receive light 24 h every day; ventilation is provided by 24.5 hp fans; electricity is used to heat the egg room; and average egg collection is 21,000/day.

Analysis of the load duration curve indicates that a 10 kW machine should be optimal for three seasons--fall, winter, and spring. The daily load profile curve varies between 6 and 13 kW. During the summer, ventilation requirements increase the load profile to 20 kW.

3.2.1 Base Case

The expected energy output is a function of a WECS power curve and the wind profile curve at the site. A wind turbine installed on a 60 ft high tower at three selected sites; 8.95 mph (4 m/s), 11.8 mph (5 m/s), 13.42 mph (6 m/s) should produce 8000; 14,350, and 22,000 kWh/yr respectively.

The breakeven period and the levelized cost of electricity for the analyzed machine appear in Table 3-3.

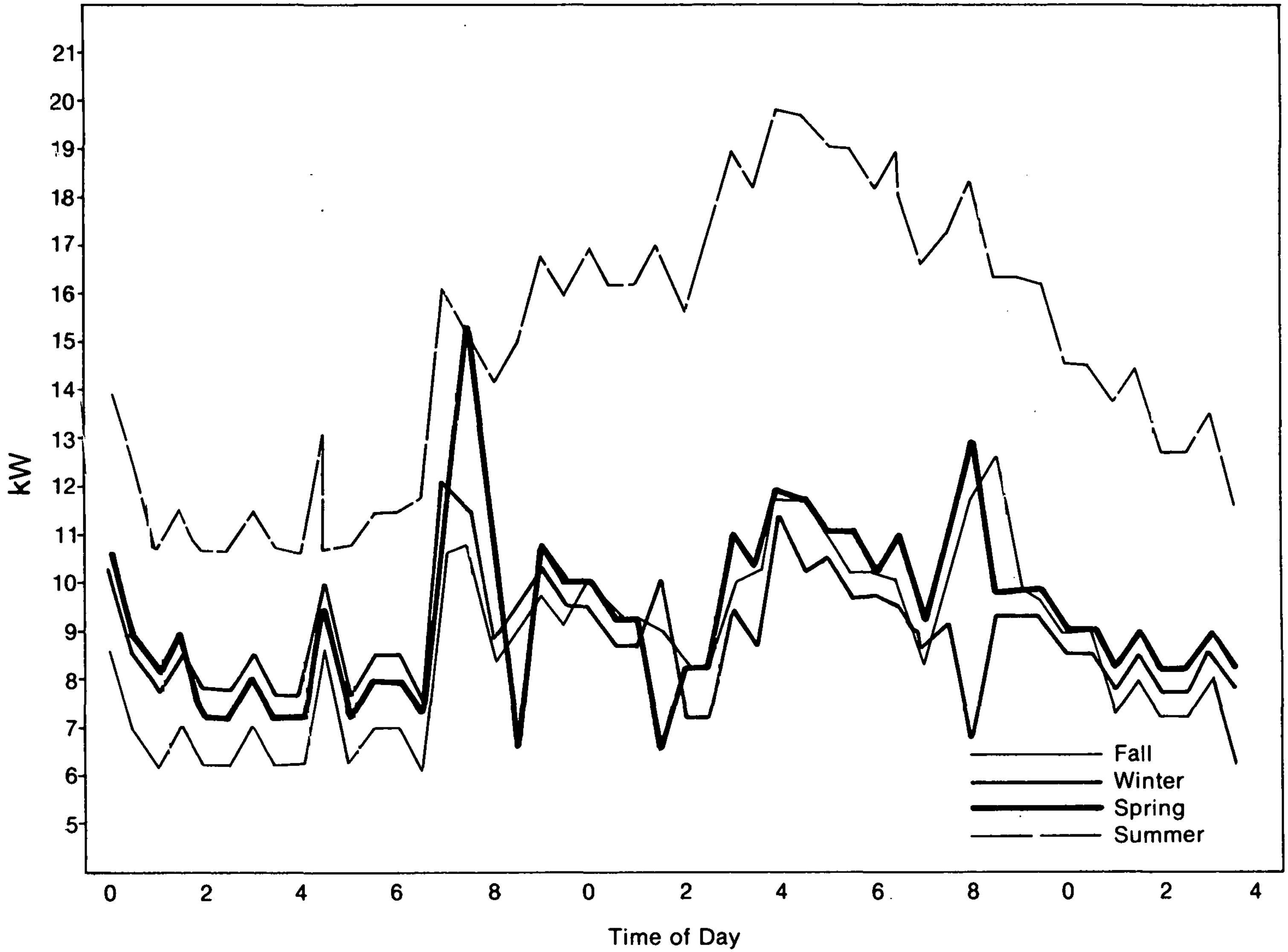
Wind resource significantly affects the performance of a WECS. Assuming a WECS utilization factor of 0.8, an increase in the wind resource from 4 m/s to 6 m/s increases expected annual output from 8000 to 22,000 kWh. Breakeven period decreases from 33 to 5 years and levelized cost of electricity produced by wind machines drops from $0.159/kWh to $0.051/kWh. The selected wind machine installed at 6 m/s average wind velocity site, with 80% utilization of output and 20% sellback to the utility at $0.021/kWh, may achieve a breakeven period of five years if the competing cost of electricity is $0.045/kWh or more.

3.2.2 Sensitivity Analysis

Figures 3-8 through 3-11 present the economic impact of installed cost, cost of competing energy, wind energy output, and utilization fractions on the breakeven period. The area below the horizontal line through six years presents required conditions to meet a six year breakeven period. Points on the horizontal line corresponding with the scale line of capital costs indicate required capital cost reduction. Table 3-4 presents the installed cost of wind systems that farmers are willing to accept under indicated conditions.

Table 3-4. IMPACT OF ECONOMIC FACTORS ON 10 kW WTG IN AGRICULTURAL APPLICATIONS

	Break-even Capital Cost $/kW at Selected Competing Cost of Electricity							
	2¢/kWh Inflated at:		4¢/kWh Inflated at:		6¢/kWh Inflated at:		8¢/kWh Inflated at:	
Site Annual Output	8%	12%	8%	12%	8%	12%	8%	12%
4 m/s Site 8,000 kWh Annual Output	200	230	350	400	480	550	680	760
5 m/s Site 14,350 kWh Annual Output	350	410	640	700	900	1,020	1,200	1,360
6 m/s Site 22,000 kWh Annual Output	540	630	1,000	1,100	1,300	1,300	---	---



Source: Wind Energy Application in Agriculture, Agriculture Research Service, U.S. Department of Agriculture, Principal Investigator Robert T. Buzenberg

Figure 3-7. Commercial User, Egg Farm

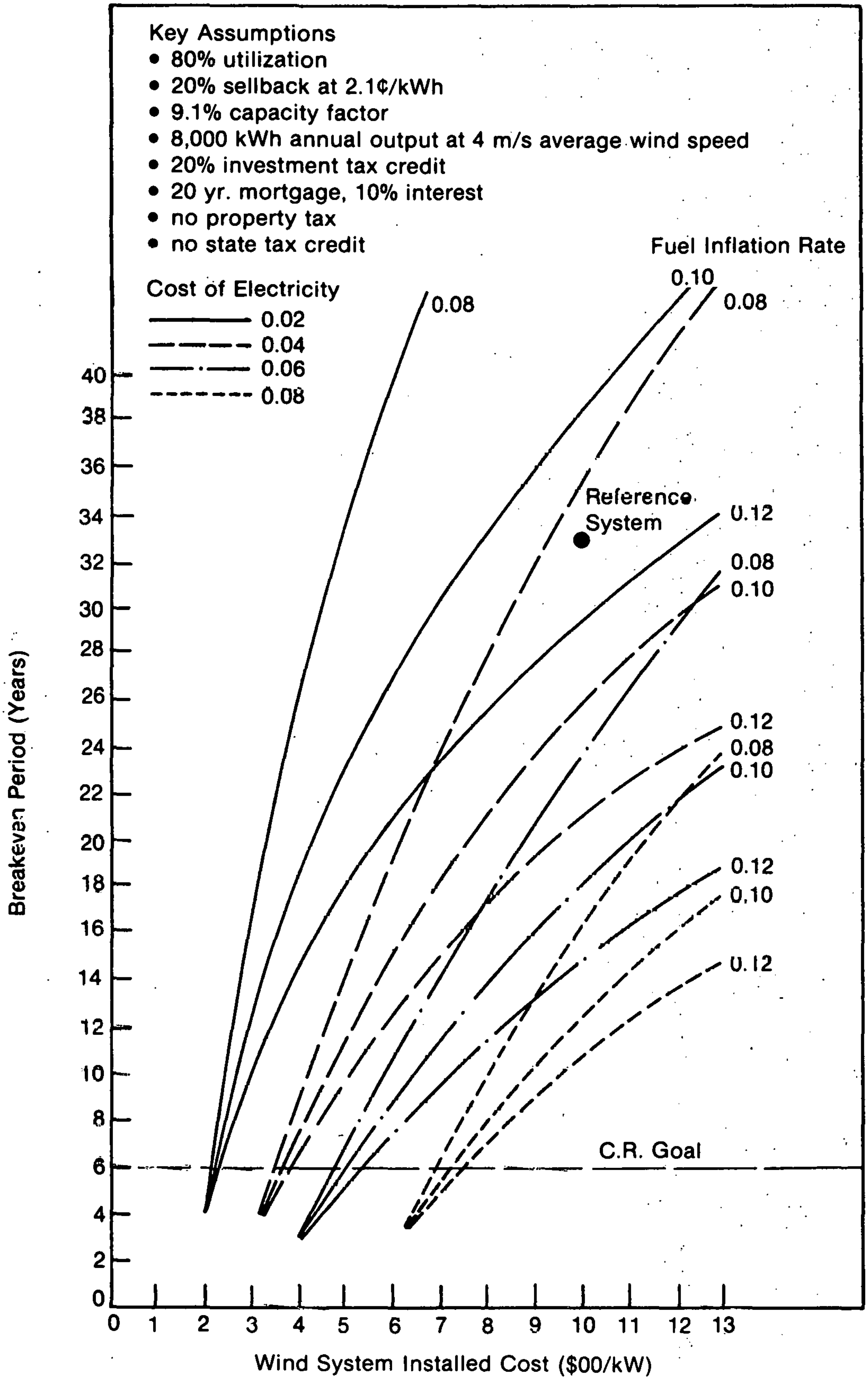


Figure 3-8. Impact of Economic Factors on 10 kW WTG in Agricultural Application, 4 m/s (8.9 mph) Average Wind Velocity Site (80% Utilization)

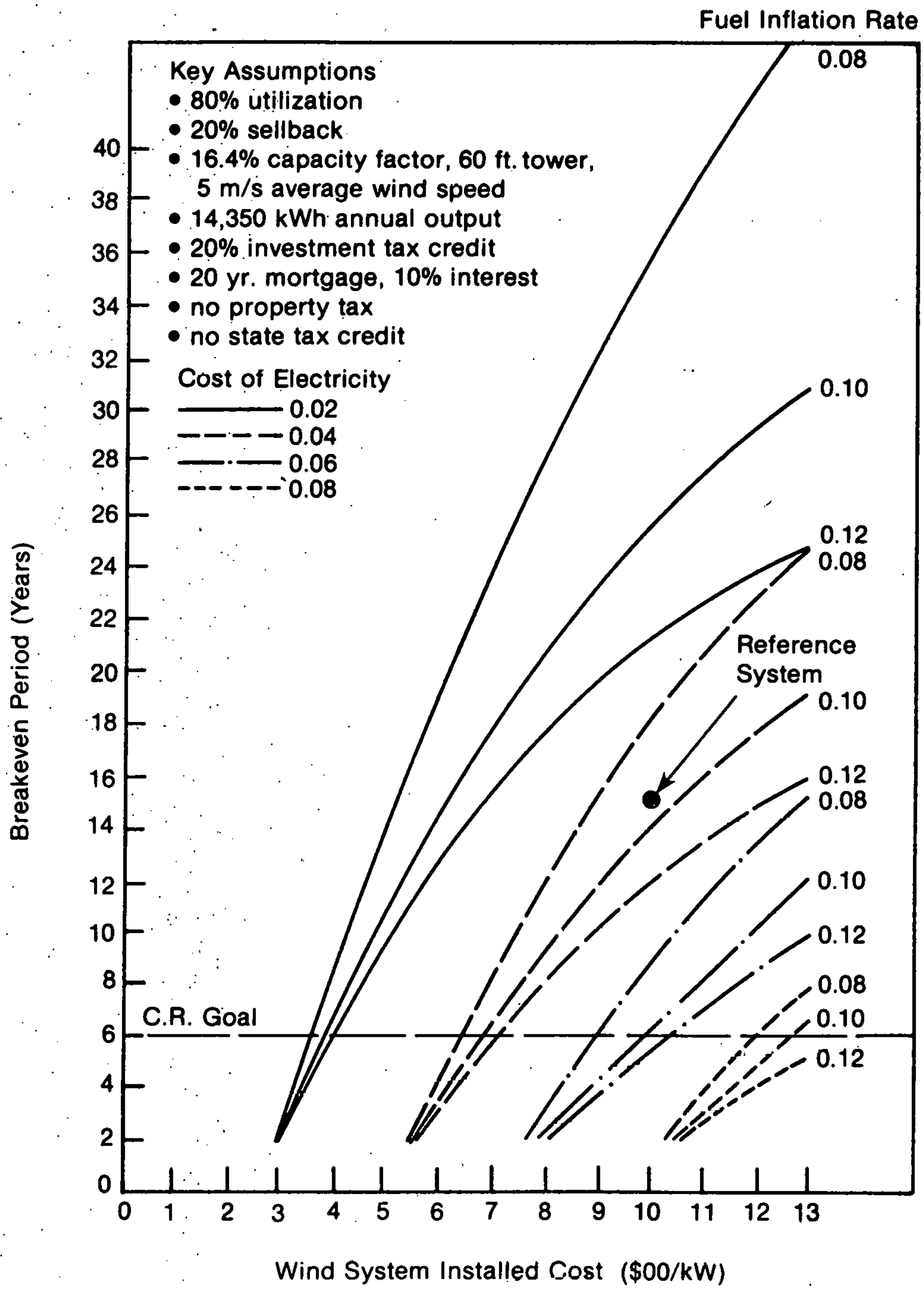


Figure 3-9. Impact of Economic Factors on 10 kW WTG in Agricultural Application, 5 m/s (11.2 mph) Average Wind Velocity Site (80% Utilization)

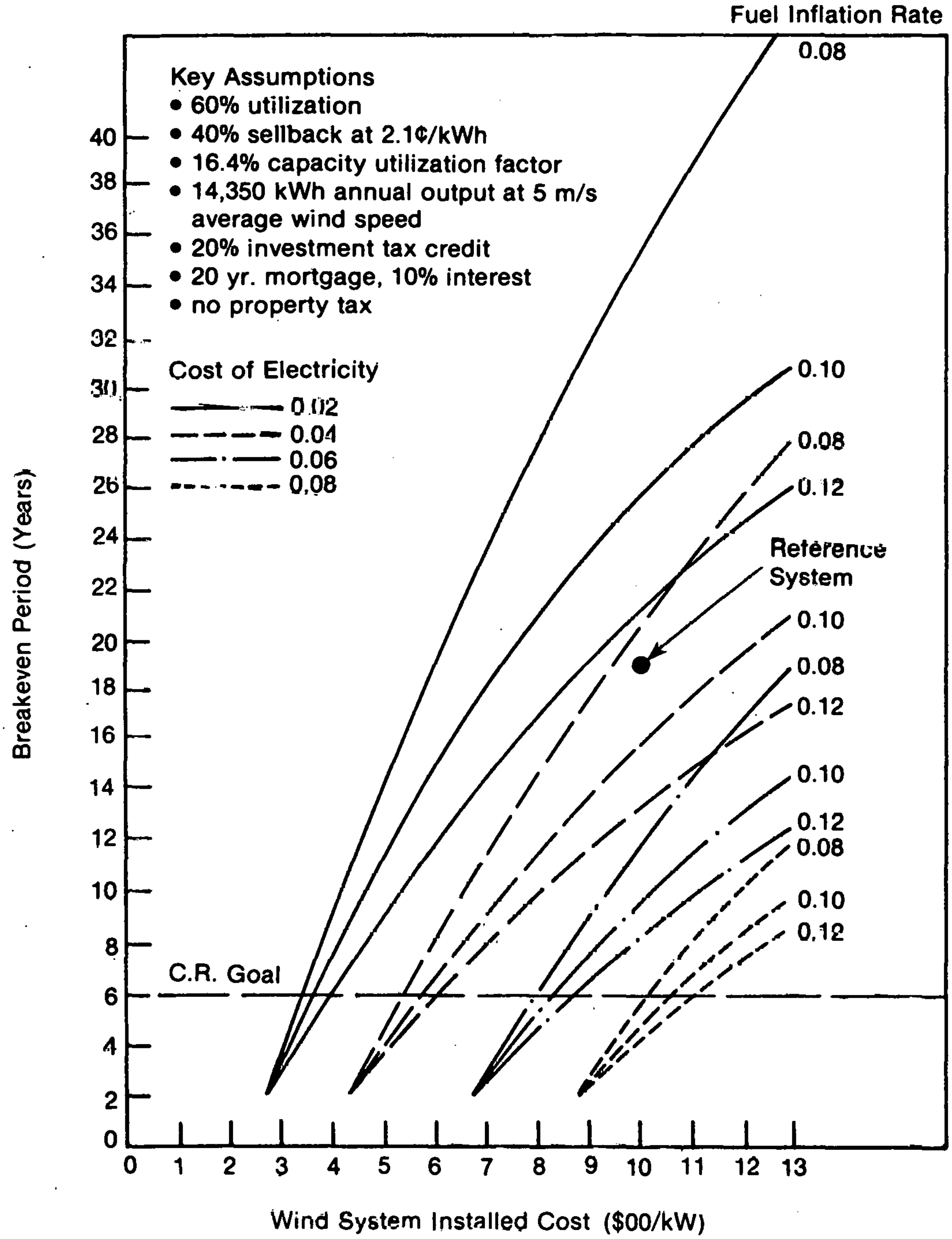


Figure 3-10. Impact of Economic Factors on 10 kW WTG in Agricultural Application, 5 m/s (11.2 mph) Average Wind Velocity Site (60% Utilization)

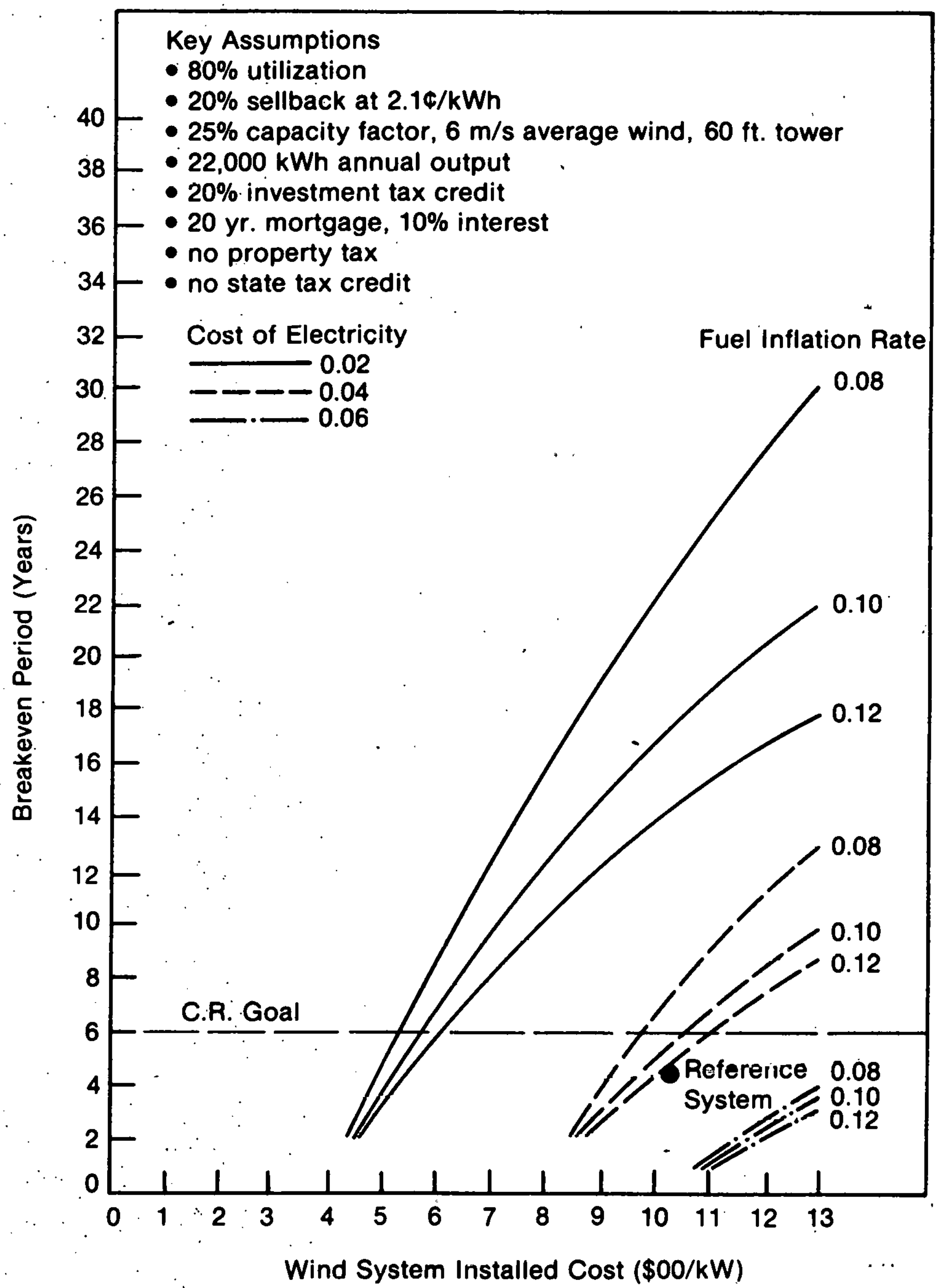


Figure 3-11. Impact of Economic Factors on 10 kW WTG in Agricultural Application, 6 m/s (13.4 mph) Average Wind Velocity Site (80% Utilization)

Document Control Page

1. SERI Report No.: TP-431-580

2. NTIS Accession No.:

3. Recipient's Accession No.:

4. Title and Subtitle

Economics of Selected WECS Dispersed Applications

5. Publication Date: April 7, 1980

6.

7. Author(s)

Stella Krawiec

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado

10. Project/Task/Work Unit No.: 6720.40

11. Contract (C) or Grant (G) No.

(C)

(G)

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered: Technical Paper

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) An economic analysis for distributed Wind Energy Conversion Systems (WECS) was conducted for the Department of Energy (DOE) as part of the Solar Commercial Readiness Assessment task at the Solar Energy Research Institute (SERI).

The major objectives of the study are to analyze:

- The cost of electricity generated by selected wind energy systems in residential and agricultural applications,
- The breakeven cost of wind systems able to compete economically with conventional power sources in dispersed applications, and
- The impact of major economic factors on the cost performance index.

Two major measures of economics used are:

- Breakeven period,
- Levelized cost of electricity (life-cycle cost).

17. Document Analysis

a. Descriptors Wind Energy Conversion Systems ; Electric Power ; Cost ; Residential Sector ; Agriculture ; Economic Aspects ; Life-Cycle Cost ; Mathematical Models ; Power Range 1-10 KW ; Power Range 10-100 KW

b. Identifiers/Open-Ended Terms

c. UC Categories

60

18. Availability Statement

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

19. No. of Pages: 38

20. Price: $4.50

Form No. 8200-13 (6-79)

° U.S. GOVERNMENT PRINTING OFFICE: 1980 - 677-175 REGION NO. 8