Analysis of Various Water Heating Systems

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This analysis examines the life cycle cost (LCC) of owning and operating a residential water heating system—the present worth of all costs of buying and owning the system over its life. These include costs of installing the water heating system and the annual operation and maintenance costs. The analysis compares the present worth of water heating systems using electric resistance, natural gas, solar with electric backup, solar with gas backup, and an electric heat pump as the sources of heat for the water. Two types of solar systems are included: active systems and integral collector storage systems (ICS).

This study includes both mortgage financing and self financing options for new houses. It assumes all water heating systems are located in the Sacramento area where Sacramento Municipal Utility District or Pacific Gas and Electric Company (PG&E) provides electricity and PG&E provides gas services. In addition, for solar and electric heat pump water heaters a lifetime air emission reduction valuation is added to the analysis as a credit. The study also examines the sensitivity of life cycle cost to varying discount rates, inflation rates, maintenance costs, solar fractions, initial costs, mortgage interest rates and energy costs (natural gas and electricity) for owning and operating an ICS-gas system and a gas water heater.

Based on average values for energy costs, discount rates, inflation rates, and maintenance costs, preliminary results show that a gas water heater appears to be the least cost system while an electric resistance water heater is the most expensive system if PG&E provides electricity. The solar system with gas backup has a lower LCC (net present value) than the active solar water heaters, heat pump water heaters, and electric water heaters.

The presentation will discuss the assumptions to which the results of the analysis are sensitive, and the values at which the solar-assisted water heating becomes competitive with natural gas water heating options.

INTRODUCTION

This study presents an analysis of the economics of alternative residential water heating systems for new construction in the Sacramento area where Sacramento Municipal Utility District (SMUD) or Pacific Gas and Electric Company (PG&E) provides electricity and Pacific Gas and Electric Company provides gas services.

Depending on their perspective, persons involved in choosing a water heating alternative for buildings may have different interests. Homeowners may be interested in the benefits they will receive, builders may wish to know the best way to market their homes, manufacturers of competing products may wish to understand how to best market their product, and government agencies may wish to know how to best serve the interests of their community.

This report provides analysis that can help each of these groups to choose the water heating alternative they believe best serves their interests. Although focused on the Sacramento, California region, the analysis can be applied to other geographic areas that have parameters within the ranges examined here. It provides homeowners with useful information to conduct their own analysis in selecting water heating systems for new homes, helps builders to determine cost effective water heating options, helps manufacturers identify opportunities to expand their market penetration, and provides information to local governments for developing local ordinances.

This analysis examines the life cycle cost (LCC) of owning and operating a water heater expressed as the present worth of all costs of buying and owning the system over its life. These costs include costs of purchasing and installing the water heating system and the annual operation and maintenance costs. The analysis compares the present worth of water heating systems using electric resistance, natural gas, solar with electric backup, solar with gas backup, and an electric heat pump as the sources of heat for the water. Two types of solar systems are included: active systems and integral collector storage (ICS) systems.

There is uncertainty regarding costs of water heating options, as well as uncertainty regarding future economic parameters. Where uncertainties may affect the relative economic ranking of options, this study examines the sensitivity of life cycle cost to varying discount rates, inflation rates, maintenance costs, solar fractions, fuel costs, initial costs, and mortgage interest rates for owning and operating an ICS-gas system and a gas water heater. Our intent is to provide readers with useful information to conduct their own assessments. Readers should obtain actual costs from local installers and qualified professionals in order to determine the cost effectiveness for their systems. As more experience with these systems is available, we expect to update our assumptions accordingly.

ANALYSIS METHOD

To compare the costs of alternative systems, a common measure is needed to compare cash inflows with outflows occurring at different times. One way to construct a common measure for cash inflows (negative value) and outflows (positive value) is to convert all cash flows to a single point in time. We used a net present value (NPV) analysis to compare cash flows. The net present value of a project is the present value of all future net cash flows from operation, plus initial investment or down payment, less the present value of salvage and emission reduction values. The current life cycle cost analysis includes financing and tax parameters. The following equation is used for calculating LCC:

LCC = + initial investment or down payment
+ present worth of annual mortgage payments on the balance of installed cost, net of interest tax deductions
+ present worth of annual energy and maintenance costs
+ present worth of capital replacement cost
− present worth of salvage value
− emission reduction valuation

The present worth for any annual costs for the life of the system can be calculated using the present worth factor. Present worth factor is defined as follows:

$$\textit{Present Worth Factor} = \sum_{n=1}^{\textit{Analysis Period}} (1 + i)^{-n} \qquad (1)$$

Where i = nominal discount rate
n = common analysis period of all systems

The annual cost to own and operate a water heating system can be calculated by multiplying the LCC present worth with the capital recovery factor as expressed in Equation (2). To express the annual cost in current dollars we use the real discount rate instead of the nominal discount rate. The system with the lowest annual cost is the most cost effective system.

$$\textit{Capital Recovery Factor} = \frac{i\,(1 + i)^n}{(1 + i)^n - 1} \qquad (2)$$

Where i = real discount rate
n = 30 years

ECONOMIC PARAMETERS

The discount rate used to adjust future costs to present value is the rate of interest that makes the investor indifferent between cash received at different points in time. The lower the rate, the greater the present value of a future cash flow. Generally, the appropriate discount rate for a person/firm is the cost of capital that represents the minimum return that must be earned for the investor's best investment. Long term and lower risk investments usually have lower discount rates, as do government discount rates for projects that satisfy a broad range of goals.

To evaluate the cost effectiveness of conservation measures, Commission staff use a three percent real discount rate. For this analysis we use a real discount rate of 3% and 10%.

The nominal discount rate and fuel escalation rate are tied to inflation rates. For this study, we used an average annual inflation rate of 3.2% that is derived from the Commission's 1996 Electricity Report gross domestic product implicit price deflator, forecast for the next 20 years. The average typical values for nominal discount rate, fuel escalation rate and mortgage interest rates used for this study are listed in Table 1.

The nominal discount rate is derived from real discount rate and inflation rate. Nominal rate is expressed in Equation (3).

$$\textit{Nominal Rate} = (1 + \textit{Inflation Rate}) \times (1 + \textit{Real Rate}) - 1 \qquad (3)$$

In the sensitivity analysis section, we use inflation rates of 0% and 5.5% in addition to the base analysis at 3.2% inflation. The average inflation from 1970 to 1993 is about 5.5% (Sullivan 1995). With the inflation rate at 5.5%, the nominal discount rate, gas, electric (PG&E) and electric (SMUD) will become 8.67%, 6.06%, 4.41% and 4.85% respectively.

The current 30 year mortgage fixed rate of interest is about 8% (nominal). The Life Cycle Costs (LCC) increase with higher interest rates. The sensitivity analysis section also addresses the effect of higher and lower interest rates on the LCC analysis.

__Table 1.__ Average Typical Nominal and Real Discount Rates and Fuel Escalation Rates

Inflation Rate	Real NA	Nominal 0%	Nominal 3.2%	Nominal 5.5%
Discount Rate	0.03	0.03	0.063	0.0867
Natural Gas Escalation Rate (PG&E)	0.0053	0.0053	0.0375[a]	0.0606
Electricity Escalation Rate (PG&E)	−0.0103	−0.0103	0.0214[a]	0.0441
Electricity Escalation Rate (SMUD)	−0.0062	−0.0062	0.0256[a]	0.0485
Mortgage Interest Rate	NA	0.08[b]	0.08	0.08

a. Energy escalation rates are derived from the draft 1996 California Energy Commission Electricity and Fuels Reports. General inflation rate is at 3.2%.
b. A fixed mortgage interest rate was used throughout the analysis independent of inflation rate.

Equipment cost and life, capital replacement and maintenance costs and annual energy usage

Table 2 shows equipment cost and life, maintenance and replacement costs, and annual energy usage for each system type (Darby 1995; Long 1996; Murray 1996; Leber, Sugar & Wong 1996). Salvage value is assumed to be zero for all systems since their ends of life coincide. No removal cost is included in the analysis. Equipment cost is based on a residential subdivision of 100 units or more and a 20% builders markup to homeowners.

Annual energy cost

The annual energy cost is the product of the energy consumption and energy rates. The average electricity rates for residential customers in the SMUD service area during 1995 is $0.082/kWh. The Commission projects this rate to escalate at a nominal 2.56% each year. In the PG&E service area the average residential electricity rate during 1995 is $0.122/kWh. The Commission projects rates to escalate at a nominal 2.14% each year.

The average natural gas costs for residential customers during 1995 is $6.25 per million Btu with a nominal escalation rate of 3.75% each year. Energy escalation rates are derived from the 1996 California Energy Commission Electricity Report. The LCC analysis is very sensitive to the fuel costs and fuel escalation rates. In the low inflation scenario (less than 3.2% per year), the fuel escalation rate would be lower.

Air emission reduction benefits

Assuming that an ICS solar water heater displaces 50% of natural gas usage, it would reduce water heater NO_x emissions by 0.99 pounds per year[1]. Table 3 shows emission factors, emission rates, damage functions, and emission reduction valuation for a Sacramento area project, and emission transaction cost for a Sacramento area project. Emission rates multiplied by the damage function give the emission reduction value to society.

In the Sacramento Metropolitan area, the market value of NO_x emission reduction credit varies widely, from $4.375 to $18.50 per pound per year depending on the available emission reduction alternatives. The emission credit value varies depending on the demand for emission credits versus the supply of those credits in a specific air basin.

The California Air Resources Board (CARB) informed the Commission that under current procedures the amount of emission reduction credits that may be available through the use of solar water heating systems may not be sufficient to justify the cost of modeling and tracking emission reduction credits for such a diffuse source (Ames 1995). CARB suggested that it was inappropriate to claim this as an economic benefit for solar water heating systems.

Even though the direct cash benefit may not be available to consumers who install the water heater, the savings that occur do accumulate as an environmental benefit for society at large. To the extent that the overall air basin emissions are reduced, this should help maintain lower transaction

Table 2. Equipment cost and life, maintenance and replacement costs, and annual energy usage

SYSTEM	SOLAR-ELECTRIC ICS	SOLAR-ELECTRIC Active	SOLAR-GAS ICS	SOLAR-GAS Active	GAS	ELECTRIC	ELECTRIC HEAT PUMP
Installed Cost	$2352	$2447	$2551	$3294	$679	$480	$1500
Equip. Life, Yrs	30	30	30	30	15	15	10
Replace. Cost	$400 @ yr 15	$400 @ yr 15	$400 @ yr 15	$400 @ yr 15	$400 @ yr 15	$400 @ yr 15	$1100 @ yr 10 & 20; and $400 @ yr 15
Maint. Cost	$75 @ yr 15	$40/yr	$75 @ yr 15	$40/yr	$0	$0	$75/yr
Energy Saved, %	48.7	58.8	43.3	44.6[a]	0	0	50
Annual Energy Usage	2.249 MWh	1.805 MWh	12.58 mmBtu	12.29[a] mmBtu	22.182 mmBtu	4.382 MWh	2.191 MWh

MWh = Megawatt hours = thousand kilowatt hours; mmBtu = million Btu
a. Reflects the displacement of 44.6% gas only and does not include additional 186 kWh electricity for auxiliary electric.

costs for other sources that may be introduced into the air basin. This last value would be difficult to estimate since it depends on a large number of factors such as population and industry growth in each air basin. We have not attempted to derive a separate value for this secondary economic effect.

As can be seen from Table 3, the highest one time NO_x emission reduction transaction cost is $18.32. This is higher than the emission reduction damage valuation of $3.50. This is a potential one time credit allowed for the first installation. This $18.32 is equivalent to an annualized valuation of $0.93 if a 3% real discount rate is used. If a real discount rate of 10% is assumed the annualized valuation will increase to $1.94. Even with the emission reduction credit of $0.93 to $1.94, this does not change the outcome of the comparison between solar-gas and gas systems. We include the emission reduction valuation of $18.32, an annualized valuation of $0.93 − $1.94, in the analysis for ICS solar water heaters. The transaction cost is likely to be different for ICS-electric systems. The transaction cost for electric would depend on the specific power plant mix that was affected by the use of the solar electric system. For simplicity, this report uses the same transaction cost for electric and gas systems.

RESULTS

The current analysis includes both mortgage financing and self financing options. For mortgage financing, we assumed that a home owner will pay a 20% down payment (initial investment) and finance the remainder through a 30 year mortgage loan at 8% interest. Mortgage interest is deducted from total income tax liability assuming a 25% tax rate. This mortgage interest deduction is the difference between the ''mortgage financing'' and ''self-financing'' analyses.

Table 4 shows the economic summary for both mortgage financing and self financing which includes first cost, maintenance costs, LCC (NPV), and average annual cost. We calculated the average annual cost by multiplying the LCC (NPV) by the capital recovery factor as defined in Equation (2).

Table 4 shows that the average annual cost for mortgage financing the ICS solar system (with gas or electric backup) is about $32 to $176 more than the gas system, depending on which utility provides electric services. The annual cost assumes a maintenance cost of $75 for one service call over 30 years. The ICS-gas system is a lower cost option than the ICS-electric system.

The active solar system (with gas or electric backup) with its capability of displacing more fossil fuel is a higher cost option than the ICS system due to higher operation and maintenance costs. If PG&E provides electricity, the most expensive system is the electric resistant type water heater, and the heat pump water heater is the next most expensive

Table 3. *NO_X Emission Factor, Emission Rate, Damage Function, Emission Reduction Valuation and Emission Reduction Offsets Credit for a Sacramento Area Project Assuming a 50% Reduction in Gas Usage*

Emission Factor,[a] lb/mmBtu	0.0895
Emission Reduction, lbs/yr[b]	0.99
Damage function,[c] $/lb/yr (1989$)	3.04
Emission reduction valuation, $ (1989$)[d]	3.02
Emission reduction valuation, $ (1994$)[e]	3.50
Emission Reduction Credit Value $/lb/yr[f](1994$)[range]	4.375–18.50
Emission Reduction Credit, $ (1994$)[g][range]	4.33–18.32

a. Compilation of Air Pollutant Emission Factors, EPA AP-42, 1993.
b. Refer to Endnote #1.
c. CEC 1992 Electricity Report, P104-92-001.
d. Based on 1989 Damage Function times the Emission Reduction value in lbs/yr.
e. The 1994 data is derived from the 1989 data adjusted at 3% inflation per year.
f. Emission Reduction Offsets Transaction Cost Summary Report for 1994, California Air Resources Board, May 1995
g. Based on Emission Reduction Credit Value times the Emission Reduction value in lbs/yr.

system due to high capital, operation and maintenance costs. However, if SMUD provides electricity, the heat pump water heater is the most expensive system analyzed.

Table 4 shows that the annual cost for mortgage financing solar assisted water heating system is about four dollars less than the self financing option. If the tax bracket increases from 25% to 37%, the annual cost for mortgage financing ICS-gas system would reduce from $222 to $211. The annual cost for gas water heaters would reduce from $190 to $187. Higher tax brackets result in a benefit to the mortgage financed solar system since it results in a larger portion of the mortgage payment being deductible.

Based on the estimated gas rates, solar system installed cost and system performance, and mortgage rate, the solar system has a higher life cycle cost than a gas water heater whether self financed or mortgage financed. However, the ICS and active solar system with either gas or electric backup have lower life cycle cost than electric water heaters and heat pump water heaters.

Sensitivity analysis

The above analyses, based on estimated average and typical values for fuel costs, discount rates and maintenance costs, conclude that gas water heater and ICS-gas water heating system are the least cost water heating systems. In this section we examine the sensitivity of life cycle cost to varying discount rate, inflation rate, maintenance costs, solar fraction, fuel costs, initial cost, and mortgage interest rate for owning and operating an ICS-gas system and a gas water heater.

Many uncertainties may affect the actual maintenance costs of the ICS-gas systems. The life of valves, glass seals, internal and external insulation, and the effects of scaling or connection failures in the collector absorber are uncertain. To explore the sensitivity of the analysis to maintenance costs, we examine a range of $0 to $150. The higher estimate, equivalent to two service calls is chosen to deal with any one or a combination of the following potential maintenance measures: 1) replace pipe insulation and/or wrap; 2) replace pressure relief valve; and 3) flush solar unit of sediment caused by scaling. For simplicity, we assume that the $75 (present value) service calls occurs in the 10th and 20th years.

Table 5 shows the annualized cost at real discount rates of 3%, solar system solar fraction of 0.433, and general inflation rates of 3.2% but varies the maintenance cost from $0 to $150. The annual gas system cost is $29 to $34 lower than the ICS solar-gas system. Even with the $150 maintenance cost, the annual cost for the ICS-gas system is at least $72 lower than the other alternatives using solar with electric backup, electric heat pump and electric resistance as the sources of heat.

Figure 1 shows the annualized cost of an ICS-gas system at real discount rates of 3% and 10%, solar system solar fraction of 0.433, 0.50 and 0.55, and general inflation rates of 0%, 3.2% and 5.5%. Natural gas nominal escalation rates are shown for 0.53%, 3.75% and 6.06% alternatives based on the forecast real fuel escalation rate of 0.53%.

Under the 0.433 solar fraction scenario, a gas system is the least cost option regardless of which real discount rate we used. With the higher efficiency solar system (0.55 solar fraction) the solar-gas system becomes very competitive

Table 4. *Project Summary for Mortgage Financing and Self Financing*

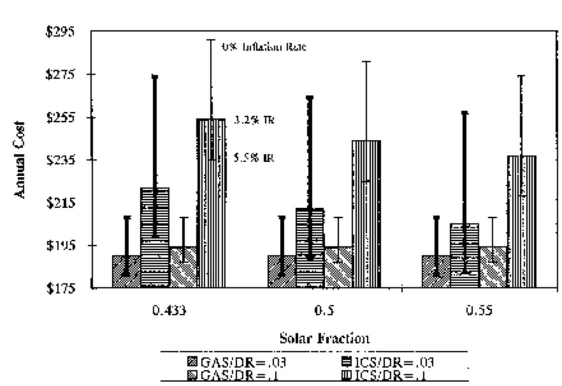
	Utility	SOLAR-EL ICS	SOLAR-EL Active	SOLAR-GAS ICS	SOLAR-GAS Active	GAS	ELECTRIC	HEAT PUMP
First Cost		$2352	$2447	$2551	$3294	$679	$480	$1500
Emission Red. Value		$18.32	$18.32	$18.32	$18.32			$20.72
Maint. Cost, PV		$48[a]	$760[b]	$48[a]	$760[b]	$0	$0	$1425[c]
Energy Cost, PV	SMUD	$3249	$2608		$1827		$6330	$3165
	PG&E	$4605	$3697	$1596	$1939	$2813	$8972	$4486
LCC, NPV Mortg Fin	SMUD	$5809	$5971		$6009[d]		$7051	$7705
	PG&E	$7165	$7060	$4348	$6121	$3726	$9693	$9026
Annual Cost Mortg Fin	SMUD	$296	$305		$307[d]		$360	$393
	PG&E	$366	$361	$222	$312	$190	$495	$461
LCC, NPV Self Fin	SMUD	$5887	$6053		$6119[d]		$7067	$7755
	PG&E	$7243	$7142	$4433	$6231	$3749	$9709	$9077
Annual Cost Self Fin	SMUD	$300	$309		$312[d]		$361	$396
	PG&E	$370	$364	$226	$318	$191	$495	$463

a. Equivalent to Maintenance Cost of $75 @ year 15.
b. Equivalent to Annual Maintenance Cost of $40/yr.
c. Equivalent to Annual Maintenance Cost of $75/yr.
d. PG&E provides gas.

Table 5. *LCC with Varying Maintenance Costs*

Maintenance Costs for ICS-Gas System	LCC /Annual Cost: Gas Water Heater	LCC /Annual Cost: ICS-Gas Water Heating System
$0	$3726/190	$4300/219
$75	$3726/190	$4348/222
$150	$3726/190	$4396/224

Figure 1. *Annual Cost with Varying Real Discount Rate, General Inflation Rate and Solar Fraction*



with the gas system under the 5.5% inflation rate and 3% real discount rate scenario.

To explore the sensitivity of the analysis to natural gas costs, we examine an increase in the real fuel escalation rate. Figure 2 shows a similar analysis as Figure 1 but varies the real gas price escalation rates from 0.53% to 1.53% instead of varying the solar system solar fraction. Under the 3% discount rate, 1.53% real fuel escalation rate and 5.5% inflation scenario, the annualized cost for ICS solar-gas system ($210) is approaching the gas system ($201). However, at the higher real discount rate scenario (10%), even with the higher inflation rate (5.5%), the gas system is still about $43 lower annual cost than the ICS solar-gas system.

All of the above discussion is based on gas prices escalated from a current gas price of $6.25/million Btu. Figure 3 shows the result of varying the current fuel cost from $6.25/million Btu to $14 per million Btu. It appears the break even point is about $9.50/mmBtu which is higher than current natural gas prices. However, this is lower than the current propane gas prices. Therefore, ICS-gas systems should be competitive in applications where the only gas alternative is propane.

Figure 4 shows LCC analysis of ICS solar water heater with gas backup with varying mortgage interest rates. It shows that with higher interest rate the annualized cost will be higher and ICS-gas will become less competitive with gas system.

Figure 5 shows the results of varying the initial cost of the ICS-gas system. A solar system with gas backup breaks even with a gas system if the solar-gas system cost is reduced to $1,900. This implies that the ICS solar portion of the system would be competitive at an installed cost of approximately $1,221.

CONCLUSION

Solar water heaters have the advantage over conventional water heaters in that they can reduce fuel costs and emissions. Solar water heaters and heat pump water heaters have inherently higher initial costs than do either of the traditional designs of gas or electric water heaters. In preparing this report, we have examined life cycle costs using a wide variety of economic assumptions for competing systems with the major focus on solar systems with gas backup and conventional gas systems.

Figure 2. *Annual Cost with Varying Real Discount Rate, General Inflation Rate and Real Fuel Escalation Rate*

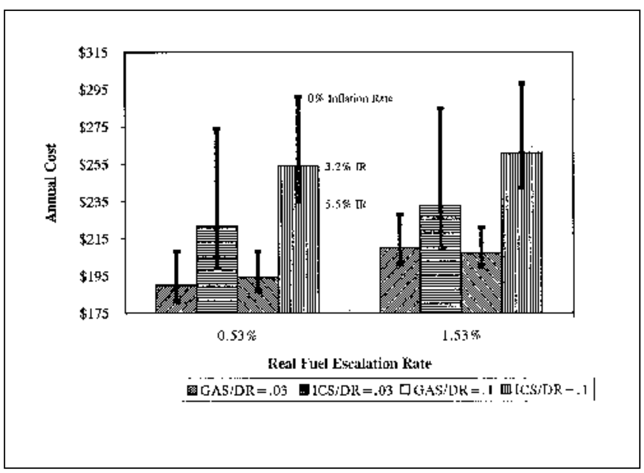


Figure 3. *Annual Cost with Varying Fuel Costs*

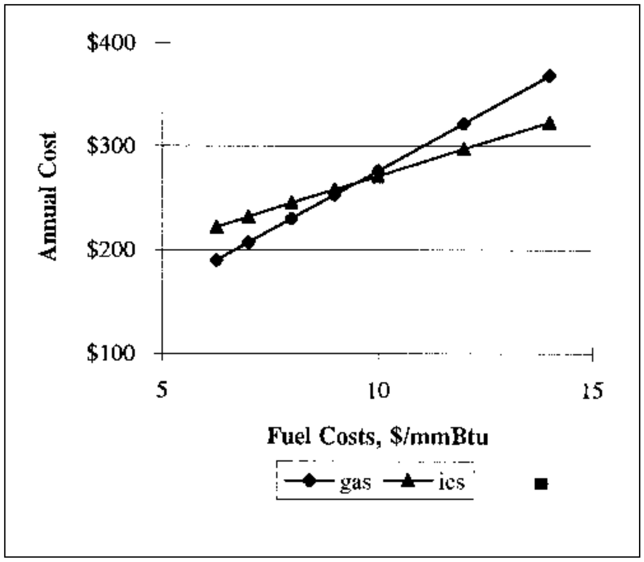


Figure 4. *Annual Cost with Varying Mortgage Interest Rate*

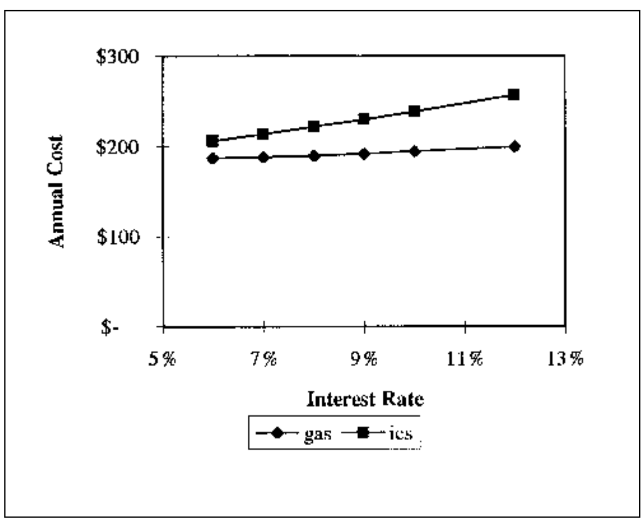
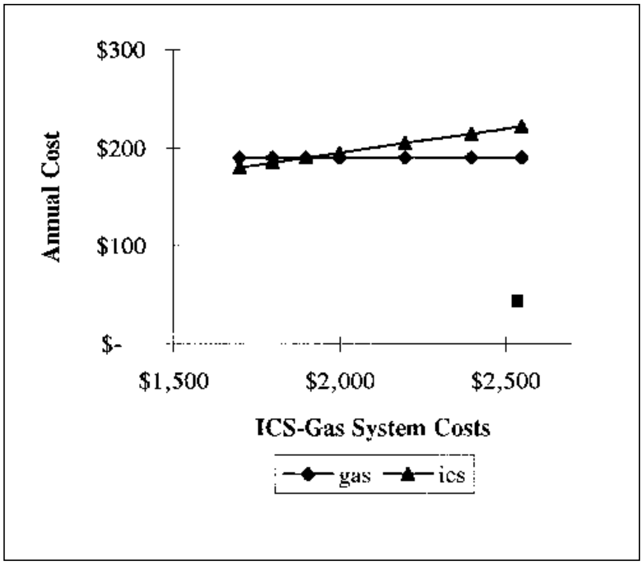


Figure 5. *Annual Cost with Varying ICS-Gas System Costs*



In the results of this analysis, gas water heating is less expensive on a life cycle basis than electric water heating. Combined ICS-propane gas system becomes the least cost option when natural gas is not available.

Among electric water heating systems, the least cost system based on life cycle costs, is an ICS-electric system. The next least cost system is an active solar-electric water heater. If electricity is provided by PG&E, the second most expensive system is a heat pump water heater and the most expensive electric option is a simple electric resistance water heater. However, if SMUD provides electricity, the second most expensive system is a simple electric resistance water heater and the most expensive electric option is a heat pump water heater.

Among the natural gas water heating options, conventional gas water heaters appear more cost effective than ICS-gas water heaters and active solar-gas water heaters. The current additional cost of adding a solar water heating system is not quite offset by the cost savings from the reduced usage of natural gas over the life of the system.

The cost effectiveness of solar-gas water heaters relative to conventional gas water heaters is sensitive to some of the economic and operational assumptions. In the Sacramento area, conventional gas water heaters appear more cost effective than solar water heaters that use these gas water heaters as their backup. Historically, maintenance costs have been a significant part of the life cycle cost of solar water heaters. Newer designs, particularly the ICS-gas system examined here, appear to have substantially lowered this cost. The difference between the extremes in the range of expected maintenance costs ($0 to $150 for the 30 year life) with these systems, about $5 per year annualized cost, has little effect on the ranking of the system.

Under current economic assumptions, a gas water heater is more cost effective than a solar-gas water heater. However this outcome could change with variations in some of the critical parameters. The most critical parameters affecting the life cycle cost are the cost of natural gas, the efficiency of the solar system, the cost of the solar system, and inflation.

If natural gas prices either rise to the current price of propane or inflate at a real rate of 1.53% per year-all else remaining the same—the ICS-gas system will be very competitive with a conventional gas water heater. If the ICS-gas system efficiency can be increased by about 25% from current ICS-gas system efficiency,—all else remaining the same—the ICS-gas system will be very competitive with the conventional gas water heater. If the solar-gas system cost can be reduced by about $650 from current costs—all else remaining the same—the ICS-gas system will be more cost effective than a conventional gas water heater. Finally, if long term inflation is as high as it was during the 1970s,—all else remaining the same—the ICS-gas system will be more cost effective than a conventional gas water heater.

Two of these critical parameters, fuel cost and inflation, are beyond the control of solar water heater manufacturers. However, the other two of these parameters, the efficiency and the initial cost, are potentially within the control of manufacturers. These two parameters represent an opportunity for solar water heater manufacturers to expand their market penetration. If they can increase efficiency while reducing costs and keeping reliability high and maintenance low, they have an opportunity to increase their share of the water heater market where conventional gas water heaters are now being used.

For communities that do not have natural gas available, leaving propane and electricity as the fuel choice options, an ICS-Solar System is a cost effective alternative to consider.

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ENDNOTES

(1) Based on an annual Natural Gas Reduction 11.09 mmBtu.
NO_x emission reduction = NO_x Emission factor $\times$ Natural Gas Reducton Rate
= 0.0895 lbs/mmBtu $\times$ 11.09 mmBtu/yr
= 0.99 lbs/yr