Economics of Solar

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ABSTRACT

Solar energy is readily available just about everywhere. It's free, uninterruptible and will be available as long as it is required. To use solar energy, however, the equipment required for capturing and converting it to useful heat or power must be purchased and installed. Essentially, with solar systems, you are prepaying for energy at a fixed rate over the solar system's lifetime. This requirement to pre-pay energy presents a difficulty in comparing the economics or effective cost and/or savings of energy delivered by a solar system to the cost of conventional energy sources.

The purchase and installation of a solar system to heat water or generate electric power essentially locks in the cost of the energy at a fixed price over the life of the solar equipment. Once a solar system is installed, the price of the energy delivered is locked in at a levelized or life-cycle cost rate based on the cost of the solar system installation, and its operating and maintenance costs over the life of the system which is between 10 and 25 years depending upon the type of system.

This article illustrates a simplified approach for developing the effective cost of solar applications to the cost of conventional alternatives. The effective cost of solar water heating and photovoltaic (stand-alone and grid-connected) systems are determined to illustrate the methodology.

Given the present uncertainty of the cost of fuel oil, natural gas and electric power, locking in the price of energy delivered by a solar system for heating water at two to five cents per kWh or $5.00 to $15.00 per million Btu is a good investment with or without the available tax credits, State and local incentives and/or environmental benefits. The economics of the photovoltaic systems varies significantly with the system type (stand-alone or grid connected) and utility rates and rate structure and is not as clear-cut as the solar thermal systems.

It is something that should be given serious consideration. At the present time, the price of solar energy applications can be locked in at a 30% discount using the federal solar tax credit that is part of the Energy Policy Act of 2005. Additionally there may be other state and local incentives that may be available for solar. The environmental benefits that range from reduction in particulate emissions and CO_2, that can earn Green Tags yielding income, to the positive image for marketing of being environmentally friendly, i.e. green hotels, encouraging ecotourism etc., also provide an intangible financial benefits for some businesses.

The information that follows in this article is intended to provide a methodology for evaluating the cost of solar energy options available to facility and energy managers to enable them to be better able to evaluate and compare solar to other alternative energy applications.

BACKGROUND AND INTRODUCTION

In these times of escalating fuel costs, and interruption, disruption or curtailment of energy supplies, building owners and managers routinely compare the cost of alternative fuels for operating equipment in their facilities. The recent escalation in energy and utility prices also has many homeowners exploring energy options. The intent is to ensure that energy for our buildings, facilities and homes is available when needed and at a price we can afford. Facility managers in industrial plants that have the capability of switching between energy sources such as natural gas, fuel oil or other energy or equipment options and alternatives recently have been exercising that option to help control costs. Facility and/or energy managers routinely monitor costs closely and consider switching from natural gas when the prices would provide an economic benefit. Many of us, however, don't take full advantage of the possible savings because monitoring fuel costs and comparing them to determine the most cost effective option for our home or workplace appears to be more trouble than it's worth.

Given the present situation in energy, it is prudent to know whether it would be more economical to use or purchase a heater that uses natural gas, electricity, fuel oil, or an Alternative energy source for providing hot water, space or process heating. Some want to consider using solar or other alternative energy sources if the cost is reasonable because it would help preserve the environment, but want to understand the economics before making a decision.

It has become apparent that it is necessary to understand the costs of our energy options and consider alternatives that might be more readily available in times of emergency or disruptions in supply or escalating prices. All energy options should routinely be compared and evaluated so that we can control the total or the life-cycle costs of owning and operating equipment in order to stay within budgets and operate most efficiently and economically. The difficulty is that the information required to compare and evaluate all energy options including solar is not readily available. The information that follows is intended to provide a simplified approach to comparing the costs of using conventional and solar or other alternative energy sources available for homes and/or businesses.

COST OF ENERGY

The energy we use for heating or power, oil, natural gas, LPG, or electric power is sold in gallons, cubic feet, pounds, therms, ccf, kWh, etc., and it is used at varying efficiencies depending upon the actual source, the specific equipment type, condition or age. Equipment manufacturers, standard organizations and the government try to help by providing the "energy consumption information" and "ratings" (% efficiency, EER, SEER, COP, etc.) but this sometimes adds to the confusion of comparing the true cost of the various options.

To effectively determine and compare the cost of energy alternatives, the output, or the useful delivered energy (heat, hot water in Btu; electric power in kWh, etc.), of the energy using equipment must be considered. The intent is to determine the cost of the individual energy sources in terms of the end product—the delivered energy. A water or space heater for example, would provide measurable heat in Btus as a function of its operating efficiency. The intent is to determine the cost of the energy units in terms of heat or electric power on a directly comparable basis, dollars per energy unit delivered, i.e. $/Btu, $/kWh, etc. Once the cost of energy for heating water in dollars per Btu delivered, if fuel oil or natural gas is the energy source, or $/kWh if electric power from a utility is the source, we will be able to determine and compare costs of alternative energy sources.

This can be readily accomplished for conventional energy sources used in heating equipment using the heating value in Btus, of the energy source used and the equipments efficiency of conversion (provided by the manufacturer) to compute a cost ($) per delivered energy unit (Btus) of hot water. A similar approach could be used for power producing equipment (solar electric systems like photovoltaics, wind energy systems or solar thermal power plants. The information that follows illustrates a simplified means of comparing costs of solar alternatives by converting the energy consumption of equipment to a consistent set of economic units as a function of the equipment being considered and its operating efficiency.

In a conventional water, space or process heating system, for example, the cost of energy in dollars per million Btus ($/MBtu) can readily be determined. The cost of heating water in an electric water heater as compared to one using fuel oil or natural gas can be calculated by multiplying the cost of energy, i.e. $/kWh for electric heating unit, or $/gallon or therm for a heater using oil or natural gas etc., by the conversion factor or quantity required for 1,000,000 Btu (1 MBtu), a standard measure, and dividing that quantity by the efficiency of use (70% for gas or oil heating, 90 to 95% for electricity, etc.) using the conversion factors and the efficiency of conversion for the individual energy sources in the equipment that will use it, i.e., water heater, boiler, air conditioner, etc.

The efficiencies (SEER, EER, COP, etc.) of specific equipment are readily available from the equipment rating published by rating organizations and available from the U.S. Department of Energy (DOE), Federal Energy Management Program (FEMP) web site (www.eere.energy.gov/femp/technologies/eeproducts).

Typical efficiencies for water heaters run between 60 and 95%, as reported by DOE (reference 1), for example, are as follows:

- Electric water heaters 92% (best available 95%),
- Gas water heaters 61% (best available 85%)
- Fuel oil water heaters 70% (best available 85%)
- Heat pump water heaters COP 3.5.

Electricity (92% to 95% efficient)

1 kWh = 3,413 Btu

293.3 kWh = 1,000,000 Btu

Natural gas (61 to 85% efficient)
1 therm = 100,000 BTU
10 therms = 1,000,000 Btu

#2 fuel oil (70 to 85% efficient)
1 gallon = 138,690 Btu
7.2 gallons = 1,000,000 Btu

LPG (61% to 85% efficient)
1 gallon = 95,475 Btu
105 gallons = 1,000,000 Btu

The cost, or value, of hot water provided by different water heaters using conventional (utility) energy sources in terms of dollars per heating energy unit, \$/MBtu, can readily be determined using the conversion factors, efficiencies and energy costs to provide 1,000,000 Btu, (1 MBtu) of hot water using the different water heaters as follows:

$$\$/\text{MBtu} = (\text{cost of energy unit}) \times (\text{energy units per million Btu})/(\text{efficiency of energy conversion})$$

Natural gas, for example, costing \$1.25 per therm (Reference 2) is provided at a cost of \$17.86/per million Btu (MBtu) when used in a water heater with a system efficiency of 70%:

$$= (\$1.25/\text{therm})^*(10\ \text{therms}/10^6\ \text{Btu})/(70\%) = \$17.86/\text{MBtu}$$

An electric water heater using electricity costing 10 cents per kWh operating at an efficiency of 95% provides hot water at a cost of \$31.00 per MBtu:

$$= (\$0.10/\text{kWh}) * (293.3\ \text{kWh}/10^6\ \text{Btu})/(95\%) = \$30.87/\text{MBtu}$$

A water heater using fuel oil costing \$2.00 per gallon operating at an efficiency of 70% provides hot water at a cost of \$21.00 per MBtu:

$$= (\$\ 2.00/\text{gallon}) * (7.2\ \text{gallons}/10^6\ \text{Btu})/(70\%) = \$20.57/\text{MBtu}$$

Considering the economics of conventional energy alternatives, the reason for fuel switching becomes obvious; there is a sizable difference in the true cost of water heating. Nowadays many commercial, industrial and governmental facilities have both natural gas and fuel oil to feed boilers and routinely monitor and switch as appropriate to avoid sudden price increases and control costs. This monitoring of energy costs and computing the cost for all alternatives on a comparable basis is also very useful when considering solar energy and other alternative energy options.

COST OF SOLAR ENERGY

The process detailed above can also be used in comparing conventional energy sources for heating or electric power to solar energy systems. To compare the cost of energy from solar systems, however, a simplified conceptual design of the solar system must be developed, and its cost and performance estimated. While such an approach might seem difficult, it is not because of the readily available information on solar system costs (Reference 3) and equipment ratings (Reference 4) available for typical solar thermal and photovoltaic systems. Using the information available on the Internet today, it is possible to put together conceptual designs and estimate system costs. Once the system has been sized, its cost and performance can be estimated, as detailed in this article, and the cost of solar energy can be determined and directly compared to the cost of conventional energy sources. In the case of solar energy, the delivered energy cost can be on the basis of a levelized, life cycle; cost for the energy the solar system would deliver over its lifetime. This levelized cost would include the cost of the solar equipment, its installation, and the systems operation and maintenance cost over its life

In the development of solar projects, economic feasibility studies are routinely performed. An audit of a project, process or facility is performed, a conceptual design developed and its performance and cost is quantified. Once the initial effort is complete, the economics of the project can be quantified. Today, many approaches are available for quantifying solar economics in project development. The economic analysis ranges from the computation of a savings-to-investment Ratio (SIR), return on investment (ROI) or simply determining the payback period. Often less tangible benefits including CO2 reduction, greening of building, and increase in property value can be significant factors that impact the final decision and economics; however, they are not considered in the analysis developed here.

The above approaches involve significant effort that requires more effort than most Facility Managers have the time to perform. Additionally, these approaches (using energy escalation and discount rates, etc. for a long-term project) lack the credibility required by most facility managers. The intent of this article is to present approaches that can be used to explore the economics of solar thermal and electric (PV) options relatively quickly with readily available information, and make a decision considering all tangible and intangible factors as appropriate for the organization's objectives and goals.

SOLAR HEATING SYSTEM ECONOMICS

A levelized cost, as illustrated above for hot water (or electric power), in dollars per delivered energy unit ($/MBtu), produced by a solar, or other alternative energy systems can be determined using a simplified life cycle cost approach. The levelized cost of solar can be directly compared to the cost of conventional energy sources to quantify the economics of solar or other alternatives. Such a levelized cost of solar energy is useful in evaluating the economic feasibility and relative economics of multiple solar applications. The approach requires determining the energy delivered by the solar system at the site of the proposed installation and the total (first cost, O&M etc.) or life-cycle cost (LCC) of the solar energy system and dividing it by the total amount of energy delivered by the solar system over its expected life (20 years for domestic hot water, 25 years for PV etc.).

$$\$/\text{MBtu or } \$/\text{kWh} = (\text{system LCC})/(\text{total energy delivered})$$

Where system life-cycle cost consists of the installed cost of the solar system plus O&M expenses over the life, generally 20 years for solar water or air heating, 20 to 25 years for PV, and 10 years for unglazed pool heating collectors.

While this approach could be more involved than necessary, the simplified approach presented in this article should be of use in developing the economics of solar or other alternative energy applications.

Example Cost of Energy of a Solar Thermal System

The energy delivered by a solar water heating system using 12 solar collectors (40 ft^2/collector) installed on a facility in Florida can be readily determined using the information on the Solar Rating and Certification Corporation (SRCC) rating sheets (Reference 3) or by computer analysis using any one of the varieties of energy system analysis programs (Reference 4) currently available. In each case the performance (energy output of the solar system) would be determined using climatic data representative of the specific site and performance characteristics of specific equipment.

It has been shown that a system analysis using a Computer Program and/or the system ratings published by the SRCC both provide a reasonable representation of the performance of the solar system in a range of climatic conditions. The computer program performs a simulation of the energy provided by the solar system over an average year using weather data from the location and the operational parameters of the system. The SRCC ratings, based on computer simulations and collector test results provide performance information in different climatic regions. The output is selected based on the specific location and climatic conditions of the site, and test data on the proposed collector and its performance. Note that in both cases, the actual performance data is based on the performance information (ratings) based on specific operational parameters and test results.

The example simulation indicated the annual energy output is 36×10^6 Btu per year, approximately 50% of the available solar energy incident upon the collectors. The installed cost of a 480 ft^2 solar water-heating system is estimated to be $36,000 ($75/ft^2) and operating and maintenance costs would be expected to add 1%, $360 per year, or approximately $7,200 over the 20 year life of the solar system resulting in a total life cycle cost of $43,200 for the installation. The energy produced by the system was estimated to be approximately 24,000 Btu/day using a second source, the SRCC Ratings for an individual collector which translates to 8,760,000 Btu/yr (8.76 MBtu/yr. The computer analysis of the system indicated the system (12 collectors) delivered 90.2 MBtu for the year. The computer analysis using site specific conditions would be expected to provide a better estimate of the actual savings and value than the more general SRCC method; however, for the purposes of a preliminary economic evaluation the SRCC approach is more than adequate. Using the results of the simplified SRCC approach and the cost and savings of the 12 collector system, the equivalent cost of the solar installation would be:

\$/MBtu = (system life cycle costs)/(energy delivered over life of system)

= (\$43,200)/[(90.2MBtu/yr) * (20 years)]

\$/MBtu = \$23.84/10^6 Btu (at the Florida location)

Comparing that projected LCC cost of the solar water heating with the cost of conventional alternatives indicates that the solar system would be cost effective when compared to electricity, slightly higher than natural gas and close to the costs of LPG and fuel oil without considering any incentives and/or other benefits (tax credits, environmental etc.) of the solar option. Given the present tax credits and incentives presently available throughout the nation, installation of a solar water heating system appears to be a good investment.

Photovoltaic System Economics

Photovoltaic systems can be used as an independent or stand-alone power source for providing electrical power or can be used in conjunction (interactive or grid-connected) with an electrical utility system. The independent PV application is intended to provide electric power directly to a load that is not connected to utility power. The stand-alone systems, however, are generally used to provide power to buildings or equipment installed at some distance from the utility distribution system, where utility grid power is not readily available or reliable.

The economics of a stand-alone system are determined by comparing the cost of PV generated power to the costs of (1) running electric power to the location or site of the equipment or (2) providing power with generators or other means at the site. The cost of electric power from a generator can be computed in the same manner as conventional thermal sources by determining the cost of operating the system, the cost of fueling and maintaining it, and the cost of the equipment or generator and its installation. The economic feasibility of stand-alone photovoltaic systems is more often than not, cheaper than the cost of providing power to sites where it is not readily available. Stand-alone PV systems are often proven to be cost effective on a first cost basis when compared to the cost of getting conventional power (utility power) or an electrical generator. The economics are not an energy issue but a total cost issue of installation and operation to the site and therefore is not discussed in detail in this article.

Given that the typical engine driven generator has an efficiency of about 30% and the present cost of fuel oil or gasoline is well above $2.00/gallon, the cost of fuel alone results in high ($0.20 to $0.60/kWh) delivered energy costs from generators. These small applications are good candidates for PV applications if the loads are relatively constant. The cost of electric power ($/kWh) from small (2,000 to 4,000 Watt) generator determined from only the fuel cost at $2.25/gallon, ranges from 25 to 60 cents per kWh. When the cost of the equipment and the cost of getting fuel to the generator are considered, the Stand-Alone PV system clearly has economic advantages over the generator.

The economics of a utility-interactive PV system, however, is a different matter. The utility-interactive system essentially displaces electric power from the utility, at the utility rate. The PV system is used on site or feeds solar power back to the utility when it is not required at the site. The economics of utility-interactive PV systems can be arrived at by determining the levelized cost of the system in $/kWh similar to the approach discussed under solar thermal systems, and can be directly compared to the cost of utility power.

One must simply determine the amount of electricity delivered by the system over its life expectancy, generally assumed to be 20 to 25 years. The power can be estimated using a variety of approaches (hand computation using climatic data and array performance (at standard test conditions, STC) but one of the simplest methods is the PVWatts program available on the web on the NREL site (Reference 4) The example economic analysis that follows compares the levelized cost of PV power to the utility power to which it is interconnected using the PV-Watts computation.

Example Cost of Energy of a Utility Interactive PV System

The energy economics of a 10.0 kW_{peak} grid connected PV system installed on a commercial building in the Space Coast Area of Florida is determined in this example. To determine the cost effectiveness of a grid-connected photovoltaic system, a cost estimate of the installed cost of the system and the expected O&M costs over its 20 to 25 year life must be developed, and the power the PV system would deliver over its life must be determined to ascertain its value.

One could use a variety of methods to estimate the system performance including computer analysis, hand computation along with weather data, which is available from NREL on the web (Reference 4) to determine the PV system performance. In any event information on the performance rating of the modules to be used on the project under standard test conditions is required. One readily available computer program that includes the weather data from the immediate area of the project site is NREL's PVWatts program, which will directly compute the annual delivered energy and cost savings.

In this example the PVWatts program is used. Note that the system size in the PVWatts program is in peak output of the PV array in direct current (DC) Watts. The program only requires one to select the location of the system, the peak power of the PV system at STC and the local utility rate or by-back rate to determine the economics. The computer analysis has a built-in system-derating factor (power losses) that appears to be fairly reasonable for typical systems and can be adjusted for specific systems as required. The system losses are a function of the modules and array, line losses and Inverter efficiency and typically run 20 to 30% when all things are considered. The default on the PVWatts program is 23%.

The PVWatts input is, for this example, 10 kW at the location of the site (Daytona Beach, FL) and the facility cost of electricity (0.10/kWh). The annual energy production from the program is 13,589 kWh, with a present value of $1,358.90, at $0.10/kWh.

To get the equivalent cost of energy simply estimate the life-cycle cost (LCC) of the installation ($8 to $10.00/$W_{peak}$) and the O&M (1/2 to 1% per year) over the 20 years and divide by the energy provided over the 20-year period. Note that cost escalation, discount rates, interest rates, inflation, etc. were not considered in this approach. The intent is to evaluate the feasibility and get a good idea of the value based on today's information.

System cost at $10.00/$W_{peak}$ = $100,000.00

Energy delivered over 20 year life = 271,780 kWh

O&M cost = $1,000/yr (1%) for 20 years

Life-cycle cost = $120,000.00

Value of energy at $0.10/kWh = $27,178.00

PV levelized cost w/o incentive = $0.442/kWh

The levelized cost or value of the grid connected system is simply not competitive with existing utility rates in most of the country. These systems are usually not cost-effective without subsidies. This issue is quite apparent and the federal government and many states have established incentives to encourage the application of PV systems to help with existing energy and environmental issues. The incentives in the form of tax credits, rebates, etc. are available and should help promote the installation of solar electric systems and further reduce their cost.

At the present time, two incentives are available in Florida, the proposed site of the example system. The State of Florida has established a rebate for PV systems at $4.00/W$_{peak}$ and the federal government has, under the 2005 Energy Policy Act, established tax credits for a wide variety of energy tax credits. Businesses and homeowner can take advantage of both of these incentives to implement solar energy systems. There are other incentives available for individuals or businesses that install solar applications in the immediate future.

Additional economic benefits are available for using green (nonpolluting) energy sources. Businesses can take advantage of accelerated depreciation that is allowed on business property that will help reduce the cost of the system, increasing the economic viability of the application. Obviously, there are other incentives and benefits available that are applicable to all renewable energy. It is recommended that the latest information on state incentives be reviewed, the possibility of Green Tags be checked to ensure that all possible assistance is identified. A source for information on the current incentives available in all the states, for businesses or individuals considering renewable energy systems, is the Database of State Incentives for Renewable and Efficiency (DSIRE) Internet site (Reference 6).

Application of the incentives available in Florida today (July 2006) for this example project reduces the cost of energy from the system from $0.44/kWh to about $0.23/kWh as follows:

PV Cost w $4/Watt state rebate:

Installed system cost	=	$100,000.00
Rebate at $4.00/$Watt_{peak}$	=	$40,000.00
Net cost	=	$60,000.00

PV Cost with 30% federal tax credit:

Tax credit	=	$18,000.00
Net cost	=	$42,000.00

Life-cycle cost	=	$62,000.00
Value of energy at $0.10/kWh	=	$27,178.00
PV levelized cost with incentives	=	$0.228/kWh (LCC/delivered energy over life)

The levelized cost of electricity from the utility interactive system located in Daytona Beach over the twenty year life of the PV system, after taking advantage of the federal tax credit and state rebate is about $0.23/kWh, 56% higher than the current rate from the utility. It should be noted that there are other potential economic benefits that can be obtained for this project. The installation provides green power, eligible for "Green Tags" which are marketable. The project also has benefit to businesses by virtue of the positive environmental action it has taken. Green hotels have an added marketing factor to attract those interested in ecotourism. Essentially, while the project might not be recommended on the basis of its economics, such a project may well move forward in today's environment in the commercial and industrial sector.

OTHER SOLAR APPLICATIONS

The approach presented in this article can be used to determine the economic viability of most types of solar or alternative energy projects. Actually, the cost per energy unit delivered can be used in checking the economics of all existing equipment, especially when different fuel types are available and being considered. As shown in the two examples discussed in detail above, all that is required is the existing cost of energy, an estimate of the cost and performance of the alternative energy system and real efficiency of the existing system-all of which can readily be obtained. On the solar side, we need system performance information from independent sources (SRCC, etc.), valid weather data, which is readily available from NREL (Reference 4) or other sites.

The determination of the solar systems performance and cost are typically the most difficult part of this approach. The performance of a solar system can be determined using the references cited in this article once the desired or expected load to be met is selected. The cost can be obtained by using the GSA schedule, which has detailed pricing available to government facility personnel. A solar contractor can verify the cost and sizing; however, the GSA pricing is valid pricing for residential, commercial and industrial personnel to use in the initial estimations.

This approach has been successfully used to determine the payback of building service and domestic water heating systems, low cost site built process water heating systems, (Reference 6) photovoltaic and geothermal systems (most of which were in fact implemented and met or exceeded the economic goals) and payback. This approach has also been used successfully in energy audits and development of a wide variety of alternative energy applications.

SUMMARY AND CONCLUSION

The approach presented in this article provides a straightforward approach to calculating a levelized cost for potential solar projects. Obviously, the approach also provides the opportunity to compute the simple payback, the most common measure used by facility personnel and energy auditors in developing and considering energy efficiency improvements.

In this article, the levelized cost is used to provide a measure of the feasibility of a solar or other alternative energy project. The life of alternative energy projects can range from 10 to 25 years, which is a long time. If the levelized cost of an alternative energy project is not less than the present day delivered energy cost of the existing system, it probably will not be considered for use in a typical commercial and industrial facility.

This approach has been used successfully in energy conservation for alternative energy project development and utility energy savings contracts. In doing this type of work, any solar projects that do not have a simple payback periods of ten years or less simply are not recommended to commercial and industrial facility managers (as an energy project). Fortunately, many solar systems do, in fact, have paybacks of 10 years or less and do provide greater savings than expected because the efficiency of the process to which they are applied was improved by virtue of having gone through the audit and efficiency improvements that are an integral part of solar project development and design.

ABOUT THE AUTHOR

Mr. Healey is a professional engineer with extensive experience in the design, acquisition, construction, installation and commissioning of solar energy projects for residential, commercial and industrial and governmental facilities. Mr. Healey has designed more than 100 solar water heating and photovoltaic projects for Commercial and Industrial facilities and been involved in evaluating and commissioning hundreds of systems. He routinely provides facility owners and managers and the solar community assistance in the implementation of solar energy systems. He specializes in the design of cost effective systems for commercial and industrial applications, assists solar manufacturers in developing installation designs capable of meeting South Florida's wind load requirements and has developed solar design, O&M training programs and manuals for architects, engineers, installers, facility managers and maintenance staff.

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