SOLAR THERMAL COMPARED TO SOLAR ELECTRIC FOR RESIDENTIAL DOMESTIC WATER HEATING

Everett M. Barber Jr.
Solar Consultant LLC
650 Leetes Island RD.
Guilford CT 06437
everett.barber@gmail.com

Abstract

Where residential solar water heating is used in the US, solar thermal systems, SDHW, have prevailed for over a century. Within the past several years, another form of solar water heating is receiving increased attention. Driving that attention are at least three factors: the on-going desire for zero emissions systems; the continuing reduction in the installed price for grid-tied solar electric, PV, systems; and the arrival on the market of unitary air source heat pump water heaters, ASHPWH. The combination of ASHPWHs, powered by grid-tied PV systems, has stirred particular interest. PV powered, storage type, electric water heaters, ERWH, are also of interest.

SDHW, PV/ASHPWH, and PV/ERWH systems are compared. Included in the comparison: long term performance of: SDHW, PV, ASHPWH and ERWH systems; installed costs for SDWH, PV; ASHPWH and ERWHs; owning costs for SDHW, PV, ASHPWH and ERWH; roof structure assessment; and added house heating load due to ASHPWH's.

1. INTRODUCTION:

Two types of residential solar domestic water heating systems are examined: one solar thermal and the other solar electric. (Note that domestic water is defined here as potable water used for personal hygiene and for washing dishes and clothes—not water used for swimming pools or for house heating.) The former system type has been in use, in various parts of the world and in various configurations, for more than a century. The latter, at least in its present form, has had very limited application, but if the installed cost of grid-tied PV systems continue to fall, and ASHPWH durability concerns are answered, it may see wider application.

Solar thermal systems for residential water heating, SDHW, are well known and should require no introduction.

Grid-tied solar electric systems, PV, supplying electricity to a residential domestic water heater, storage type with electric resistance heater, ERWH, are relatively scarce, due mainly to the high cost of the solar electric system needed to power the ERWH. Solar electric systems supplying electricity to an air source heat pump water heater, ASHPWH, are also not widely used since the product is relatively new, but they require less electricity than an ERWH, and thus may find wider acceptance.

The heat pump is hardly a new concept, having been in use in various forms since about the 1930's. Refrigerators and window air conditioners are both heat pumps. During the mid-1970's and early 1980's there was a flurry of interest in ASHPWHs. Those products were configured as separate heat pump packages and then piped to existing storage type domestic water heaters. Their promise: to reduce the energy required for heating domestic water compared to ERWHs by as much as 50%. That was a realistic expectation for a heat pump; however, due to durability issues and to a scarcity of competent maintenance, the product did not survive in the marketplace.

Over the past several years there has been renewed interest in ASHPWHs for residential water heating. Two factors are driving this interest. The first is the continued drop in the installed price of grid-tied solar electric systems. Installed prices for these systems have dropped from about $12/Watt dc 15 years ago, to about

$5.00/Watt dc presently. The second factor is evolving ASHPWH technology. The US DOE has invested in developing ASHPWH technology. It made that technology available to the water heater industry. Additionally, the ASHPWHs of today bear little resemblance to those of the 1970's. The systems of today are unity systems, that is, all the components, the heat pump, the tank, and the supplemental heater are integrated in one package. Field tests of these systems indicate annual coefficients of performance, COPs, of about 2.3, provided the systems are properly sized, installed, and maintained.

SDHW and PV/ASHPWH and PV/ERWH systems for residential domestic water heating applications are compared below. Among the factors included in the comparison: long term performance of SDHW, grid-tied PV systems, and ASHPWH's; installed prices for those systems; owning costs which include maintenance, longevity of major components, removal and remounting of the arrays for reshingling; roof structure assessment where required; and the added cost of house heating due to the ASHPWH's

2. PERFORMANCE DATA

Performance data for both solar thermal and solar electric systems is needed for the installed price and owning cost analyses.

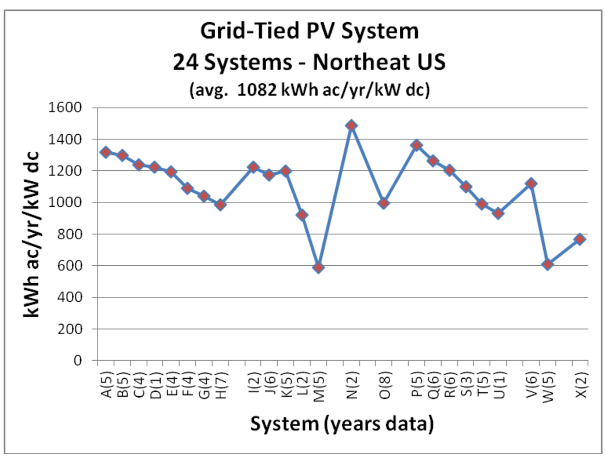

Fig. 1: Actual Output – Grid Tied PV Systems.

The above shows the actual annual output of 24 residential and commercial grid-tied solar electric systems. Average output of all systems shown, excluding "n2," (sun-tracking) is 1,082 kWh ac/ft^2/yr. per kW dc. That can also be expressed as 16 kWh ac/ft^2/yr.

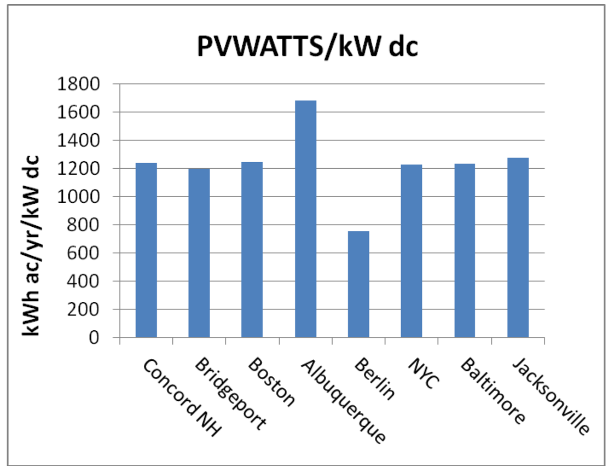

Fig. 2: Predicted Output of Grid Tied PV Systems.

The above shows the predicted annual output of grid-tied PV systems in selected localities. There is little variation over much of the Eastern US. In localities where trees are common, the actual output of many PV systems is often 15 to 20% lower than the model prediction, due to shade from limbs of deciduous trees after leaves have fallen.

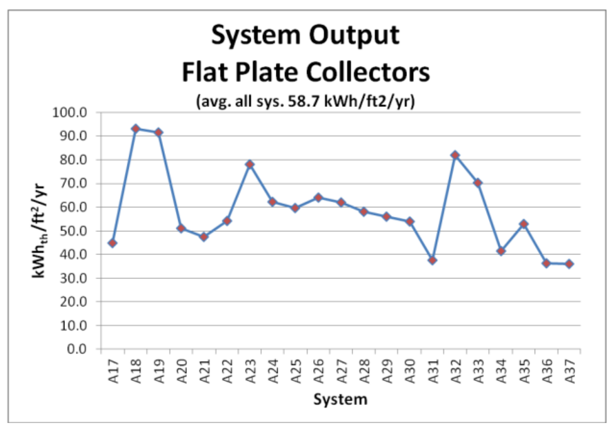

Fig. 3: Actual Output of Solar Thermal Systems w/Flat Plate Collectors

Above is the annual energy delivered by 21 solar thermal systems with flat plate collectors. Systems used for domestic water heating and, in some cases, for space heating. This data came from an Internet survey of third-party test results of solar thermal systems conducted by Emaan (Amy) Ammar and the author. The average output for the 21 systems is 58.7 kWh ac/ft^2/yr.

3. CHARACTERISTICS OF SYSTEMS

3.1 Standalone vs. Combination System: To make a straightforward comparison between the two system types, each was considered here as a single purpose, or stand-alone, system.
The PV/ASHPWH may be sold as part of a larger solar electric system for whole-house loads. In that case, the cost of PV system components would be a portion of the cost of the larger system. The same goes for maintenance costs. This could make the owning cost of the PV/ASHPWH system closer to, if not less than, that of the SDHW system. A SDHW system is typically sold as a stand-alone system, and thus repair costs would not be prorated. However, as with the PV/ASHPWH, it may also be sold as part of a larger solar thermal space-heating/pool heating system, in which case those costs could be prorated. It should be noted that the energy from a residential solar space heating system is not used year-round, unless pool heating is used.

3.2 Structural Analysis: The local building official may require an opinion letter from a licensed structural engineer vouching for the structural integrity of the roof before either type of solar array can be placed on a roof. The opinion letter can cost between $700 and $1,500.

3.3 Roof Resurfacing: Shingled roofs typically need reshingling every 20 to 25 years. If either type of solar array is installed over shingles, it should be removed when a new layer of shingles is applied or when shingles are replaced, which usually occurs after two layers of shingle have been placed on a roof. The removal and remounting is often a significant and unexpected cost to the home owner. Many SDHW systems installed during the mid-1970's and early 1980's were removed at this juncture in ownership.

3.4 Tree Limb Shade: The branches of deciduous trees after losing their leaves, will reduce the solar gain to either type of solar array by a measured 30 to 65 percent. Tree, or limb, removal can be costly.

3.5 Repair vs. Replace: The owning cost of a given ASHPWH system will be affected by the service tech's decision to repair or replace the system. While the least cost to the home owner may be the repair of a component by a knowledgeable technician, it is often easier—and more profitable—for a technician, especially a less knowledgeable one, to replace an entire system than to figure out how to make the repair. SDHW systems, which are not so tightly integrated, are more amenable to individual component repair/replacement. Repair or replacement of an ERWH is mostly limited to replacing an electric element or replacing the entire water heater.

3.6 Tank Sizes: While the heat pump is a more efficient way to heat water than an electric resistance element, it heats the water more slowly. To provide an adequate supply of hot water for most draws, the heat pump tanks have a larger volume than the typical 40gal. (151. l) ERWH. For a given hot water demand, the larger the ASHPWH tank size, the higher the percentage of water heated by the ASHPWH. Typically ASHPWHs use 65 (246. l) or 80 gal. (303. l) tanks. Test data indicates that if properly sized for the load, the ASHPWH can operate with a coefficient of performance of about 2.3. By comparison, the tank sizes for SDHW systems having a solar fraction of 0.80 or more are typically 120 gal. (454 l), with 80 gal. (303. l) the smaller size used.

3.7 Interior Space Requirements: ASHPWHs require much more interior space than the conventional storage type water heaters that are used with ERWH's or SDHW systems. Several ASHPWH manufacturers require the water heater be placed in a space 700 to 1,000 cubic feet (20 to 28.3 m^{3}) in size. Most ASHPWH manufacturers explicitly state the heaters should not be placed in closets.

3.8 Increased House Heating Load: The ASHPWH draws heat from the surrounding atmosphere. During the cooling season, that heat (and moisture) removal is usually welcome. During the heating season, that heat removal will add to the cost of heating the house. This is not a concern with SDHW systems or ERWHs.

3.9 Array Placement: Where available collector array area is limited, the greater output per unit area of a solar thermal system may influence the water heating system choice. A solar thermal system will produce almost four times as much energy per square foot, or square meter, as a PV/ERWH, and about 1.5 times as much when compared to a PV/ASHPWH.

3.10 System Reliability: Some contend that PV systems are more reliable than SDHW systems. If an SDHW system is designed & installed by an experienced person then it will require very little maintenance. Most solar thermal systems installed in the US are of the filled, pressurized, indirect type. They tend to require more maintenance than partially filled, unpressurized, indirect systems, also known as drain back systems. The latter, when glycol is the coolant, are, by far, the least troublesome.

3.11 Noise: The ASHPWH's are noisier than either the ERWH or SDHW systems. The noise is considered objectionable if the unit is in the same room with an occupant, but less so if it is in an adjoining room.
3.12 Condensate Removal: ASHPWHs require piping for removal of condensate from their evaporator coil. The condensate flow can be by gravity to a nearby drain, or to a reservoir with a float activated pump to lift the condensate to a drain. The condensate line must be cleaned regularly, yearly is common. This is similar to condensate removal from the evaporator of an air conditioning unit. Neither ERWH nor SDHW require condensate removal.

3.13. Owner Oversight: Conventional water heaters are usually the sole source of hot water for a home. If the water heater fails the owner knows it simply because there is no hot water. Both SDHW and PV/ASHPWHs include a supplemental water heater. The SDHW may stop working for some reason, causing the supplemental heater, if it is not turned off, to provide all of the hot water. Several weeks or months may pass before the owner notices that the solar component is not working. Similarly, the PV/ASHPWH will revert to heating water with 100% electric resistance heating if the owner fails to notice the heat pump component is not working. Too cold an environment, for instance, could cause the ASHPWH to shut off.

4. INSTALLED PRICE AND OWNING COST :

For the majority of consumers, installed price, (cost to the consumer) is the sole consideration driving the purchase of a water heater. Consumer preference for the lower installed price is borne out by the overwhelming number of storage-type natural gas and ERWH heaters sold in the United States compared to the higher installed price for more efficient types of water heaters such as the instantaneous gas-fired water heater or HPWH. Nonetheless, there exist a substantial number of consumers who will purchase a water heater if the cost over some period of years, owning cost, can be shown to be less than that for a lower first cost heater. Other benefits, such as environmental, may also influence those buyers.

Renewable energy incentives are politically enacted to encourage the use of efficient products. They can, depending on the type of incentive, significantly reduce either the higher first cost, or the owning cost of such products.

Both installed prices and owning costs for the systems under discussion are presented below.

4.1 Installed Price Comparison:

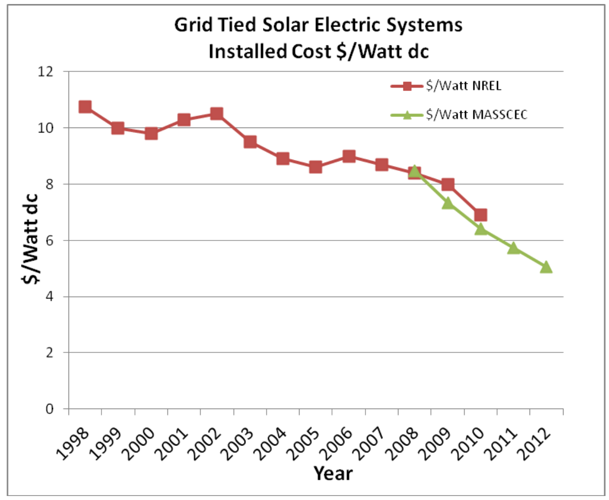

Fig. 4: Grid Tied PV $/Watt Installed:

The above indicates the trend in the installed price for grid-tied PV systems since 1998. Both commercial and residential systems are included.

Table 1 (See page 8) shows the Installed prices for residential SDHW systems in two US regions.

The decline in grid tied PV system installation price is certainly ongoing, but where the installed price, currently about $5.00/watt dc in the US, will level off is anyone's guess. Also uncertain is the impact that expected tariffs, imposed on China to offset their dumping of PV modules and cells in the US, will have on the continued decline in PV system costs. Tariffs of between 75% and 250% are being discussed.

Unlike PV systems, SDHW system prices seem to vary widely across the country, with most contractors charging what the market will bear. It remains to be seen the extent to which competition from PV/ASHPWH's will affect the SDHW system prices.

4.2 Impact of Financial Incentives:
Various incentives meant to stimulate the use of renewable energy equipment have been enacted at both the federal and state government levels. While incentives can be very effective tools for promoting one technology over another, they are far from permanent, or fair. Many incentives reduce the installed price of a system, while others reduce the owning cost. An example of the former is the Federal Income Tax Credit

(FITC), which allows solar system buyers to subtract 30 percent of the installed cost of a system from their federal income taxes. The present solar FITC is set to expire at the end of 2016. An example of the latter is the production credit, such as Solar Renewable Energy Credits, or SRECs. This gives system owners a credit for the energy produced by the system over some period of time—15 years, for instance.

Incentives were not included in this analysis because they vary so widely from state to state and from one technology to another, and because they are constantly changing at the state level. (For detailed, current information on the federal, state, and local incentives, go to www.dsireusa.org and search the region of interest.) In general, solar electric systems receive more incentives than do SDHW systems.

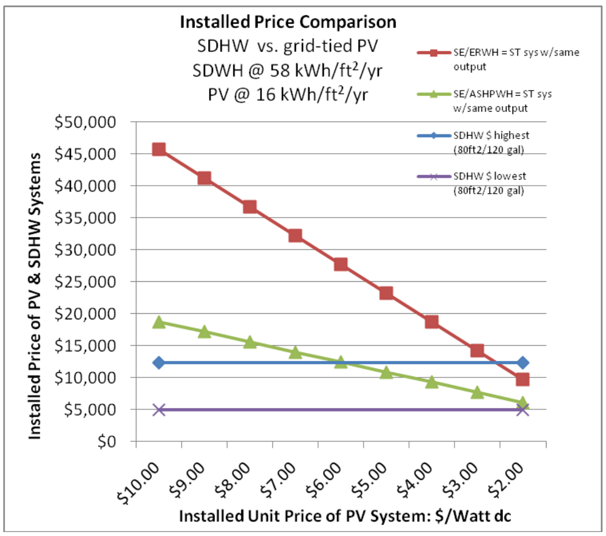

FIg. 5 Installed Price Comparisons:

The above is based on the performance data for SDHW and grid tied PV systems given in figures 1 and 3 above. The SDHW system size was chosen to deliver a solar fraction of about 0.85 (as predicted by the computer model F-Chart). Domestic water heating with (solar) electricity is examined in two ways: by an ASHPWH and by a standard (ERWH.) The three solar systems were sized to produce the amount of energy consumed by heating 64 gal (242 l) of 120 F (49 C) water per day. The annual EF for the ERWH was 0.88 and the annual COP for the ASHPWH was 2.3.

4.3 Example Installed Price Comparison:

Refer to Fig. 5. A grid-tied PV system supplies electricity to an 80 gal (303 l) ASHPWH. The ASHPWH was estimated to use 1735 kWh/yr. Its installed price was $3000. The PV system yields 1100 kWh ac/yr/kW dc, and has a unit cost of $5.00/Watt dc. The PV system installed price would be $7887. The figure indicates that the combined cost of the PV system and ASHPWH would be approximately $11,000, before incentives. To find that figure, enter the Fig. 5 at $5.00/Watt on the horizontal axis; go up to the sloping line with the triangular plot symbols, then horizontally across to the vertical axis, to ~ $11,000. Since there is a rather wide variation in SDHW system installed prices, two horizontal lines are used on the chart to represent that variation range. Those lines represent the likely maximum, $12,000, and minimum, $5,000, installed prices of SDHW systems that produce a solar fraction of >0.80. See Table 1 on page 8. Assume an average figure of $8500 for the installed price of the SDHW system. Find that figure on the left vertical axis of Fig. 5. The intersections of the sloping solar electric water heater lines with the horizontal SDHW lines indicate the points of equal price. For this example, the intersection of a horizontal SDHW line for $8500 with the inclined line for PV/ASHPWHs occurs at about $3.50/watt. Thus at about $3.50/watt the PV/ASHPWH and SDHW systems are equal in installed price. A similar comparison between SDHW and PV/ERWH can be made on the same chart. Using $8500 for the SDHW system, the two systems would be comparable in an installed price of at about $1.75/Watt.

4.4 Owning Cost Elements

The owning cost is typically calculated over an extended period. In this case that period was 25 years. The components of the owning cost include the installed price, as above, the cost of fuel to run the system, the maintenance required to repair or replace the system; and the longevity of system components.

4.4.1. Installed Costs

These are a part of the owning cost. They are as in 4.1 above.

4.4.2. Fuel cost

An estimate of the fuel cost to operate a given water heater is usually made by calculating the load, in this case the water heating load, and by using published data for the efficiency of the appliance (or, in its absence, measured fuel-cost data) and local fuel cost data. A spreadsheet was developed to estimate the energy requirement and consumption for 15 different types of water heaters, using both conventional and renewable sources of energy. While fuel cost escalation rates are at times included in owning cost analysis that was not done here.

4.4.3. System Longevity

The average life of nearly any product is represented by a bell-shaped curve whose peak is the "average" life. Some products fail sooner than average, others fail years later. The longevity of ASHPWHs and SDHW systems are discussed below.

The longevity of the unitary ASHPWHs is difficult to prognosticate. It is critical to the outcome of this comparison with SDHW systems. The ASHPWHs are a new product. Historically, their lack of longevity was the reason they disappeared from the market. The present unitary ASHPWHs might last only 7 to 8 years, because the compressor, or the microcomputer fails; or the tank leaks; or a heat exchanger is fouled by deposits. The more often the system, or its components, must be replaced, the higher the 25-year owning cost. While most of the ASHPWH warrantees are for 10 years, those cover materials only, labor and shipping must be borne by the owner. Also, the warranty on a replacement heater typically does not last beyond that of the original purchase.

We have no long-term experience with the present configuration of ASHPWH. If we base their expected service life on experience in the 1970s and 1980s, then 2 to 3 years might be a realistic estimate. However, it is likely that the major appliance manufacturers now producing them have improved their longevity well beyond that. Another aspect of an ASHPWH's longevity is installation and service. They're typically installed by a plumber but often must be serviced by a technician with a refrigeration mechanic's or heating contractor's license. The new systems include the heat-pump compressor, evaporator, condenser, storage tank, microprocessor, and supplemental electric resistance heater as an integral unit. They are indeed a tightly integrated system. If the tank leaks, the entire unit must be replaced. If the compressor fails, it is likely that the entire unit will be replaced. For the owning cost analysis, a 10-year life was assumed, since most of the units carry a limited 10-year warranty.

There is a very informative on-line forum on ASHPWHs that anyone considering them should read: http://www.thetankatwaterheaterrescue.com/forums/forum3/2544-1.html The forum began in early 2010.

How long will an SDHW system last? We have a good deal more experience with them. Assume that the SDHW system considered here is for residential use, and is an indirect, forced-circulation system which is probably the most common type in the United States. Based on the author's 40 years of experience with this technology, well-built collectors should last at least 50 years. The life of the solar preheat tank will depend on its construction, the chemistry of the water it contains, its maximum temperature, and other variables. A likely range for average tank life might be 8 to 15 years. See below for more about the tanks. The balance of system components, such as the piping, coolant, circulator, pump control and sensors, can be expected to last at least 20 years. Exterior pipe insulation will last between 7 and 20 years, depending on the quality of the insulation and its jacket.

Assume that the PV system considered here is for residential use and is grid-tied without battery backup. The PV system may be paired with a conventional storage-type electric resistance water heater (PV/ERWH) or with an PV/ASHPWH. Based on about 25 years of experience, the PV modules should last 20 years, at least. Out gassing has occurred in 20 to 30 year old modules. The more recently made modules may last longer. The longevity of inverters is a question. Of 24 grid-tied PV systems the author has been tracking for up to 9 years, about 40 percent of the inverters have needed replacement. Improvement in product quality is ongoing. For this analysis, the average life of an inverter was assumed to be 12 years. Manufacturer's warrantees are typically 5 to 10 years, but longer are available, at additional cost. The balance of system components, such as the wiring and combiner box and roof flashing, should last at least 20 years. See below for more about the expected life of tanks and the ASHPWH.

Hot-water storage tanks are common to both the solar thermal and solar electric system configurations. Tank construction varies, but the most common domestic hot-water tank by far is made of hot-rolled steel with a glass frit lining fired to the interior. The life of such a glass-lined steel tank depends on its construction and to a large extent on the water chemistry. If the water to be heated is acidic, with a pH between 5.0 and 6.0, the tank may last no more than 7 to 9 years. If the pH is 7.0 or higher, then the typical tank may last 15 years, perhaps longer. Note that most domestic hot water tanks carry a 5 or 6 year warranty, some manufacturer's offer a 10 year warranty, at extra cost.

Readers wanting to know more about ASHPWH performance are referred to a recent, comprehensive study of ASHPWH's by Steven Winter Associates. See Ref. (1)

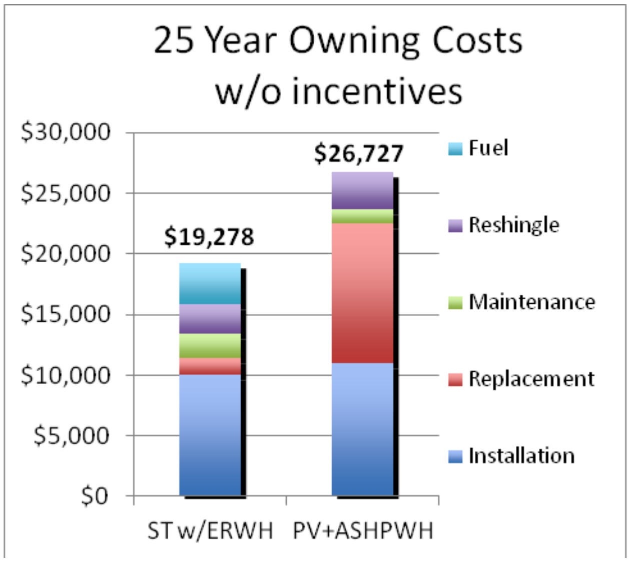

Fig. 6: System Owning Costs – 25 years

The chart shows the estimated cost of ownership of two types of solar water heating systems over a 25-year period. One is an SDHW system including collectors, solar preheat tank (PHT), and a separate ERWH as the supplemental heater. The other is a PV/ASHPWH. See Table 3 (page 8) for "Detailed Assumptions"

TABLE 2: SUMMARY ASSUMPTIONS - FIG. 6

	ST w/ERWH	PV+ASHPWH
Installation	$10,000	$11,019
Replacement	$1,458	$11,458
Maintenance	$1,944	$1,250
Reshingle	$2,500	$3,000
Fuel	$3,375	$0
Total	$19,278	$26,727

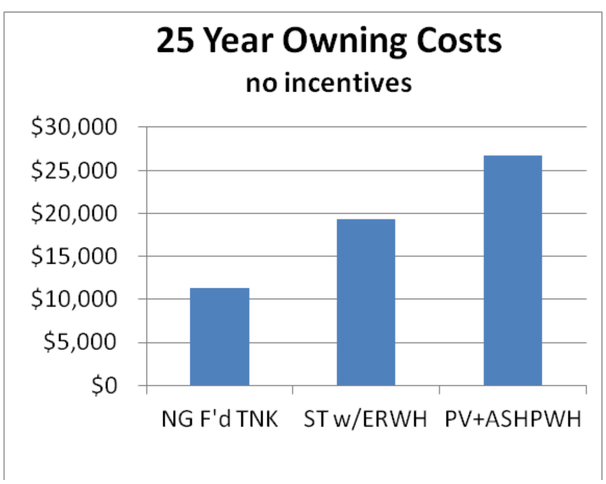

Fig. 7 Owning Cost Comaprison – Solar w/Nat Gas.

Above shows the two solar water heating systems compared to a typical natural gas fired, storage type, water heater.

5. CONCLUSIONS

5.1: Zero Emission Systems: The PV/ASHPWH and the PV/ERWH water heaters if sized to supply 100% of the DHW load are both zero emission solutions for residential domestic water heating. The SDHW will provide most of the water heating without emissions, but will usually require some energy for the supplemental heating and that may not be from a renewable source.

5.2 Site Considerations: Both types of solar systems require adequate roof or ground area for the solar arrays. Neither system works well unless tree and tree limb shade is eliminated or minimized. The SDHW and PV/ERWH systems will not require nearly as much interior space in the residence as the PV/ASHPWH.

5.3 Mature Technology: The SDHW and ERWH system have been refined over a much longer period of time than the ASHPWH. The latter, in its present form has been on the market for less than 5 years.

5.4 Installed Price: On the basis of installed price, and ignoring incentives, the PV/ASHPWH is about equal to the SDHW system at an installed price of about $3.50/Watt for the PV/ASHPWH. The PV/ERWH is about equal to the SDHW system at an installed cost of about $1.75/Watt. Current installed price in the US for PV systems is about $5.00/Watt dc.

5.5 Owning cost: Over a 25 year period, and ignoring incentives, the SDHW system is less expensive than the PV/ASHPWH. But when incentives are applied, the two are close in owning cost. In fact, incentives often favor PV systems over SDHW systems. Where this is the case, the owning cost of the PV/ASHPWH can be less.

5.6 Longevity: The outcome of the owning cost comparison will be determined by the longevity of the ASHPWHs. If the ASHPWHs last between 15 and 20 years, then that system may be the winner.

5.7 PV System Installed Price Trend: The decline in grid tied PV system installation price is ongoing, but where the installed price, currently about $5.00/Watt dc in the US, will level off is anyone's guess. Also uncertain is the impact that expected tariffs, imposed on China to offset their dumping of PV modules and cells in the US, will have on the continued decline in PV system installed prices. Tariffs of between 75% and 250% are being discussed.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

(1) Steven Winter Associates, Inc. Heat Pump Water Heaters – Evaluation of Field Installed Performance, June 26, 2012

TABLE 1: INSTALLED PRICES FOR SDHW SYSTEMS – TWO REGIONS

Installed Prices for SDHW Systems - Two Regions

7/1/2012

Sized for: 64 gal/day (242 lpd); 120 F (49 C) water	High Sys. $	High $/ft^2	Avg. Sys. $	Avg. $/ft^2	Low Sys. $	Low $/ft^2
A. NorthEast						
80 ft^2/120 gal-indirect; complete sys. w/up to 250 ft insulated Cu tube; ~$8.00/ft >250 ft; ~0.85 solar fract.	$10,000	$125	$8,500	$106	$7,000	$88
B. North Florid**a**						
64 ft^2/80 gal-indirect; complete sys. w/up to 120 ft insulated Cu tube; ~$6.00/ft >120 ft; ~0.85 solar fraction			$7,775	$122		

TABLE 3: DETAILED OWNING COST ASSUMPTIONS - 25 YEAR OWNERSHIP:

	non-renewable	renewable/non-renewable	renewable
	NG F'd TNK	ST w/PHT-ERWH	PV+ASHPWH
Total Cost over 25 years	$11,352	$19,278	$26,727
		Conservative Scenario	
water heating load/yr	22.7MM Btu/yr	1038 kWh/yr	ASHPWH: 1735
fuel cost	$1.40/CCF	$0.13/kWh	$0.13/kWh
fuel cost escalation	0%	0%	0%
installed cost of sys	$900.00	$10,000: ST Sys.+ERWH	$8,019 solar+$3000 HPWH
FITC	not apply	30% (not used)	30% (not used)
state rebate	not apply	not used	not used
local SREC	not apply	not apply	not used
Replace convent. Htr.	$900: / 8 yrs.	$700: / 12 yrs	not apply
Replace ASHPWH	not apply	not apply	$2500: /10 yrs
Replace inverter	not apply	not apply	$2500: /12 yrs
Replace solar array	not apply	not required	not required
ST sys. maint.	not apply	$700: /9 yrs	not apply
PV Sys. maint.	not apply	not apply	$300.: /5 yrs
R&R Array: Reshingle	not apply	$2500: /20 yrs	$3000: /20 yrs.
Tree Shade Removal	not apply	ignored	Ignored