

White Paper

Solar Thermal Energy: The Time Has Come

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Solar heating, often overshadowed by photovoltaic systems, is the most cost-effective on-site renewable energy resource. It presents vast opportunity for public and private organizations to save on fossil fuels, cut costs, and reduce carbon emissions.

The technical potential for solar water heating in the United States is about one quadrillion Btu of energy savings per year, worth $8 billion of energy costs and 50 million to 75 million metric tons of carbon dioxide emissions. Furthermore, some 67 percent of the nation's commercial buildings have rooftops available for solar water heating, according to the National Renewable Energy Laboratory.[1]

These figures may be merely theoretical, but they illustrate the vast possibilities for solar thermal technology to displace fossil fuels, counteract climate change, and save building and business owners money. While solar photovoltaic and wind power tend to dominate the news, solar thermal remains the most cost-effective source of on-site renewable energy. It typically costs less to install and pays back faster than photovoltaic energy. Common uses include swimming pool heating, boiler water preheating, domestic water and space heating, air conditioning, and heat for a wide range of commercial and industrial processes.

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In the nonresidential sector, users of solar thermal technology include hotels, hospitals, prisons, restaurants and cafeterias, government buildings, universities and schools, athletic facilities, manufacturing plants, and laundries.

Solar heating helps users diversify their energy supplies and reduce dependence on imported fuels with volatile pricing. Solar systems can meet 50 percent of a typical facility's hot-water heating load and may meet up to 80 percent. Even in northern climates during winter, systems can provide 20 percent or more of water heating requirements. (What matters is the annual performance of a solar water heating system and not the seasonal performance, unless the facility's thermal needs are strictly seasonal.)

A commercial solar water heating system with 500 square feet of collector will displace the hot water generated by a small natural-gas-fired boiler, generating 2,281 therms per year and offsetting more than 26,825 pounds of CO_2. On a larger scale, solar thermal energy creates economic development and local jobs in manufacturing, installation, operations and maintenance.

The solar collection technologies are field-proven. In the past 15 years, product research and development and improved manufacturing have created a new generation of simple, reliable, efficient solar water heating systems. Modeling tools are available to predict system performance, costs, energy savings and return on investment based on local sun and weather conditions. Clearly, solar thermal has earned a place in the national and global energy mix. In fact, solar water heating has the potential to be the largest contributor in the next growth era of renewable energy and emission reductions.

Taking the long view

At present, solar thermal technology faces some headwinds, but longer-term trends appear to work in its favor. For the time being, the price of natural gas – the main fuel solar heating displaces – are at low levels as hydraulic fracturing (fracking) operations dramatically increase domestic supplies. At the same time, commodity prices for glass, copper and aluminum used in solar thermal collectors are rising as the economy improves. There is also a shortage of contractors trained in solar thermal installations, and the same financing obstacles exist as for solar thermal as for many types of renewable energy. Finally, prospective users of solar thermal energy may not fully understand it or appreciate its versatility and value.

All these conditions are likely to be temporary. Fuel and commodity prices are cyclical by nature. As recently as three years ago, natural gas prices stood near historic highs. Prices may rise again as the U.S. exports more gas, as utilities add gas-fired peaking power plants and replace older, polluting coal-fired power plants used for base load with smaller gas turbines. Also with potential to tip the scale are more production of liquefied natural gas (LNG) for export and wider acceptance of compressed natural gas (CNG) as a fuel for buses, taxis, cars, and a wide assortment of fleet vehicles.

Meanwhile, other trends in markets and government policy tend to brighten prospects for solar thermal energy. The industry continues to develop materials and heat-transfer technologies that make solar heating more efficient. The industry is also moving toward more standardized "plug and play" systems that make procurement more efficient, limit product and site engineering costs, and simplify installation.

Solar thermal also fits with a growing trend among organizations to make public commitments to save energy and reduce greenhouse gas emissions. In the Institute for Building Efficiency's 2011 Energy Efficiency Indicator survey, 76 percent of respondents said their organizations had either an energy-reduction or carbon-reduction goal, and 36 percent had both.[2] Renewable energy also contributes points toward green building certification under the U.S. Green Building Council's LEED® program.

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Growing numbers of states and utilities offer incentives and rebates for renewable energy installations. In addition, renewable portfolio standards (RPS) have been passed in 33 states, requiring utilities to derive specified percentages of their power from renewable sources. Electric utilities, municipalities and some state legislatures have developed incentives and marketing campaigns using photovoltaics to meet RPS requirements. A simple and reliable metering technology could enable conversion of solar thermal energy to its kilowatt-hour equivalent, allowing solar water heating or cooling to count toward RPS compliance, as well. A growing number of states now allow solar thermal projects to qualify for utility incentives or may qualify for renewable energy credits (RECs) under their RPS programs.

A typical residential-sized solar water heating system produces 7 to 10 kWh per day, or 3,400 kWh per year, depending on local conditions and type of collector and system design. On average, for each such system installed, 0.5 kW of peak demand is deferred from the utility's load. When a utility solar water heating program like Hawaii's has thousands of solar water heaters displacing electricity, the demand reduction is measured in megawatts.

More opportunity than meets the eye

The principle behind solar thermal energy is simple: A solar collector absorbs heat from the sun, and fluid warmed by passing through tubes in the collectors is distributed to the appropriate system. The basic technology has existed for more than 100 years, and systems have been proven to last more than 25 years – longer than a conventional water heating system – at a fraction of the life-cycle cost. Solar collectors can be installed anywhere on a facility with adequate access to unobstructed sunlight. Estimates show that tapping the United States' full potential for domestic and commercial solar water heating could:

- Save 578 billion cubic feet of natural gas per year – 2.5 percent of the nation's usage.
- Save 35 billion kWh of electricity per year, just under 1 percent of U.S. consumption.
- Prevent 52 million metric tons of carbon dioxide emissions annually, equivalent to the emissions from 13 coal-fired power plants or 9.9 million cars.[3]

The most widespread solar thermal application is water heating. It uses simple components – solar collectors, pump, controller, storage tank, heat exchanger and circulation system – that can be easily integrated with a building heating system. Typically, systems circulate a glycol solution so that they can continue functioning in cold weather. Other solar thermal applications include:

Pool heating. Solar heating systems can warm indoor or outdoor pools in almost any climate. The existing pool filtration system often can be used to transfer heat from the solar collectors to the pool water.

Space heating. Similar to solar water heating systems, these systems generally use more solar collectors, larger storage units, and more sophisticated designs. They may use a non-toxic liquid, water, or air as the heat-transfer medium from the solar collectors.

Cooling. Here, solar heating systems are coupled with absorption chillers and use a thermal-chemical sorption process to produce air-conditioning without electricity. The process is like that of a refrigerator except that there is no compressor. The absorption cycle is driven by a thermal transfer fluid – heated water or glycol mixture – from the solar collector. Water cooled to about 44 degrees F runs through copper piping, and forced air passing over the piping produces air conditioning.

Despite the high potential, solar thermal capacity in the United States lags behind much of the world. For example, on a per-capita basis, the nation ranked 35th globally in solar water heating (excluding swimming pools) – although such installations have increased over the last five years, grew by 10 percent in 2009, and increased by another 5 percent in 2011 despite a slow economy with historically low natural gas prices.[4,5,6]

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Catching the sun

Many organizations fail to benefit from solar thermal energy largely because they do not know the many possibilities it offers. There are three basic levels of solar thermal energy:

- Low-temperature (80 to 100 degrees F) for purposes such as swimming pool heating and boiler water preheating.
- Medium-temperature (100 to 160 degrees F), largely for domestic/service hot water heating and space heating.
- High-temperature (180 to 350+ degrees F) for industrial processes and air conditioning.

A variety of technologies deliver these levels of solar heating, and they break down into four categories, based on the types of solar collectors.

The simplest systems heat water directly in unglazed, dark-colored **polymeric tubes or mats** exposed to the sun. These highly efficient low-temperature systems require large-area collector arrays. They heat water to a maximum of about 105 degrees F and are used mainly for swimming pool heating. Thermal output can be as high as 1,000 Btu per square foot per day. Installed costs range from $17 to $50 per square foot.

Flat-plate collectors, used for domestic water heating or space heating, generally consist of a dark-colored absorber plate inside an insulated metal box with a glass cover, glazed to help keep solar radiation from leaving the container once it has entered. Sunlight striking the plate is transferred to a fluid that circulates through the collector in tubes. These systems can heat one to two gallons per day per square foot of collector area. The maximum temperature largely depends on the temperature of the feedwater. For example, a 4-foot by 10-foot collector (40 square feet) in south Florida, with a typical groundwater temperature of about 70 degrees, would heat an 80-gallon tank of water to 140 degrees. Installed costs for flat-plate systems range from $80 to $160 per square foot.

Evacuated tube systems do the same basic work as flat-plate collectors but perform better in cold climates because the vacuum inside the tubes reduces heat loss from conduction and convection. The basic structure includes a glass tube made of borosilicate glass that allows sunlight to pass through, and a black-coated copper or aluminum absorber inside the tube. The performance advantage over flate-plate systems is not significant in warmer climates, except where users desire very hot water, as for a commercial process.[7] Installed costs are about the same as or higher than for flat-plate systems.

Micro-trough solar heating systems, which use parabolic reflectors to focus sunlight on a receiver, can achieve temperatures from 160 to 350 degrees F. They are used mainly for space heating, industrial process, and solar air conditioning (when coupled to absorption chillers). Micro-troughs depend on direct-beam radiation as in the desert southwest and track the sun in a single axis (east to west) for maximum heat generation. Flat-plate or evacuated tube systems actually perform better in areas with hazy sunlight or diffused radiation such as the Gulf Coast.

Knowing the technologies and their limitations is important in selecting the right technology for the job.

When is solar thermal attractive?

Solar water heating systems can be highly cost-effective in facilities that have constant or even intermittent hot-water demands. Other forms of solar heating can be economical in a wide range of settings, depending on heat requirements, local climate and sun conditions, and other factors.

Nonresidential solar heating systems generally require professional design and sizing. A key step is to determine the heat or cooling load to be met. In particular, sites like manufacturing plants, commercial laundries, hotel kitchens and restaurants require higher temperatures and appropriate sizing. Determining the feasibility of solar thermal for a given application is largely a straightforward process.

The evaluation rests on an audit that includes a solar access inspection to make sure the site has adequate access to sunlight. Some sites may be clearly unsuitable because of excessive shading. At others, inspection personnel may need to use a solar access tool to make sure enough solar radiation exists for enough hours per day. The ideal location allows the collector array to face south, although orienting it within 45 to 90 degrees east or west of due south can be satisfactory.

A thorough audit also includes inspections of the roof (if the system will be mounted there), water heater, electrical system, and plumbing to make sure these facilities are sound and have no issues that could adversely affect the solar heating installation. A solar thermal energy specialist then can specify the type and size of collector array and other components to meet the heat requirement.

Once those steps are complete, commercially available modeling tools can accurately predict the cost of the system, the thermal output, and the economic benefit, measured in time to achieve positive cash flow. Most off-the-shelf solar collectors have been certified by the Solar Rating and Certification Corporation (SRCC) to specify what their energy output should be under specific local sun conditions.

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Solar thermal technology is part of a $4.1 million performance contract for improvements to help Bowie State University become climate-neutral and support the EmPOWER Maryland initiative.

Solar thermal systems at work

Here are a few examples of how solar thermal energy is helping users save energy, cut utility costs, and reduce emissions, as stand-alone projects and as part of larger facility upgrades.

Pool-heating project pays back in 3.5 years

Glen Hills Middle School in Glendale, Wisconsin, saves $5,000 a year and expects a 3.5-year payback on a solar pool heating system. The school's main boiler heated the pool and therefore had to operate year-round. Now flexible solar collectors use the heat of the sun to warm the water, reducing or eliminating the need to use the boiler in summer, thus saving natural gas and reducing greenhouse gas emissions. A thorough analysis of the district's energy bills, analysis of the pool heating requirements, and a calculation of potential savings helped the district qualify for state and local utility grants that paid for two-thirds of the project.

Solar supplements biomass heating

Mount Wachusett Community College in Gardner, Massachusetts, installed a solar thermal system for domestic water heating, augmenting its commitment to combating climate change. A biomass heating system had reduced campus electricity use by 38 percent, but when it was taken offline for the non-heating season, water was heated with electricity. The solar system eliminates that electricity. The system consists of 12 rooftop solar collectors. Utility incentives totaling $18,000 helped pay for the project. The water heating system is one of 11 energy conservation measures the college is undertaking to help reduce electricity usage by 15 percent, saving more than $129,000 annually. The college is also deploying wind energy, geothermal and a photovoltaic projects and so will host five different renewable energy sources.

Solar thermal helps toward climate neutrality

Solar thermal technology is part of a $4.1 million performance contract for improvements to help Bowie State University become climate-neutral and support the EmPOWER Maryland initiative, which calls for state buildings to reduce energy usage by 15 percent by 2015. The James Gym swimming pool on the campus was fitted with a solar heating system to supplement the existing heat exchangers that warm the pool, saving on fossil fuel and utility costs and extending boiler life. The overall project, with a Metasys® building management system, lighting retrofits, tighter building insulation, HVAC equipment upgrades, and more, was expected to reduce annual consumption by 2,040,775 kWh of electricity, 107,938 therms of natural gas, and 7,771,000 gallons of water. The university will emit 1,593 fewer tons of carbon dioxide per year, equivalent to taking 283 cars off the road or heating 125 homes for a year.

Recommissioned hot water system adds to savings

A U.S. Department of Energy Super Energy Savings Performance Contracts (ESPC) helped the Denver (Colorado) Federal Center complex of more than 90 buildings upgrade to increase energy efficiency and achieve $450,000 of annual savings. Besides lighting retrofits, HVAC equipment upgrades, and new high-efficiency chillers and pumps, the work included recommissioning of a solar hot water system and installation of solar panels that were installed on the childcare center to showcase renewable energy to children. Water savings from the project total nearly 11 million gallons per year, and emissions have been reduced by more than 16 million pounds of carbon dioxide, 40,500 pounds of nitrogen oxides, and 93,600 pounds of sulfur dioxide.

Making the commitment

Opportunities for solar thermal energy are available to almost any organization. A company with expertise in solar energy can help evaluate the possibilities, select the most appropriate technology for the site, and model the costs, savings and cash flow.

It is prudent to select a project partner that understands not only solar energy but also how to integrate a thermal system with the existing building heating system, cooling system, or process, and with the building or process controls. A well qualified supplier will also have access to innovative financing programs and will be able to help secure rebates and other incentives from utilities and federal and state governments.

Solar thermal is a highly cost-effective way to deploy renewable energy, reduce long-term operating costs, and make progress toward sustainability or green building goals.

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About the author

As Director of the Solar Heating and Cooling business with Johnson Controls, Inc., William T. Guiney is responsible for solar thermal programs and technologies. He has more than 30 years experience in the solar industry as a contractor, educator, distributor and manufacturer, has provided renewable energy and energy efficiency training programs, and is an instructor for solar thermal energy systems at the North Carolina and Florida Solar Energy Centers. He has served on the solar thermal technical committee of the North American Board of Certified Energy Professionals (NABCEP) and was chair of its Thermal Entry Level Committee. Guiney is also co-chair of the Texas Renewable Energy Industries Association solar hot water committee and has previously served on the board of directors of the Wisconsin and Florida Solar Energy Industries Associations.

Resources

[1] The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States. National Renewable Energy Laboratory, Technical Report NREL/TP-640-41157, March 2007.

[2] 2011 Energy Efficiency Indicator Survey, Institute for Building Efficiency.

[3] Smart, Clean and Ready to Go: How Solar Hot Water Can Reduce Pollution and Dependence on Fossil Fuels. Wisconsin Environment Research & Policy Center, March 2011.

[4] Werner Weiss and Franz Mauthner, International Energy Agency, Solar Heat Worldwide: Markets and Contributions to the Energy Supply 2008, 2010.

[5] Solar Energy Industries Association, *U.S. Solar Industry Year in Review 2009*, April15, 2010.

[6] SEIA/GTM Research U.S. Solar Market Insight 2010 Year in Review.

[7] It is proven that flat-plate collectors perform better than evacuated tubes in areas with snow in winter, as the insulated evacuated tube does not re-radiate heat to melt the snow off the collector. The typical heat loss of a flat-plate collector will melt snow and start generating energy on clear days. Typically, a flat-plate collector is the first thing on a roof to become free of snow.

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