6. Solar Heating and Cooling: Technologies, Cost, and Performance

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6. Solar Heating and Cooling: Technologies, Cost, and Performance

6.1 INTRODUCTION

Unlike PV and CSP technologies, solar heating and cooling (SHC) technologies produce thermal energy, not electricity. In residential and commercial buildings, the most widespread SHC technology is solar water heating (SWH); solar space heating and cooling are emerging applications. Other SHC applications include process heating or cooling for manufacturing, food processing, and other industries; district heating and cooling; and agricultural applications such as crop drying. SHC displaces thermal energy sources such as natural gas and propane as well as electricity. Thus, although SHC does not produce electricity, it complements the Vision solar electricity targets by displacing electricity and fossil fuel use.

Today, more than 146 thermal gigawatts (GW_{th}) of SHC capacity are in operation worldwide. In fact, SHC technologies are the world's largest source of solar energy, exceeding the capacity and energy production of PV and CSP combined (Weiss et al. 2009). The International Energy Agency (IEA) referred to renewable energy heating and cooling as the "sleeping giant" of world renewable energy potential, with the market for thermal energy constituting 40%–50% of worldwide energy demand (IEA 2007).

By the end of 2009, solar pool heating constituted over 21 GW_{th} of the nearly 24 GW_{th} of total SHC capacity in the United States. SWH for buildings accounted for 2.1 GW_{th} (SEIA 2010). The potential for U.S. SHC growth is large. Although recent government policies have not focused on renewable thermal energy, incentives similar to those provided for other solar technologies could build the U.S. SHC market as they have in other countries. Because SHC technologies offer significant greenhouse gas mitigation potential at a relatively low cost, policies restricting greenhouse gas emissions would make SHC technologies more attractive. See Chapter 2 for more information on the current market status and resource potential of SHC technologies.

This chapter provides information on today’s SHC technologies, SHC cost-reduction and technology improvement opportunities, and the materials, manufacturing, and labor resources available for scaling up SHC production and implementation.

6.2 TODAY'S SOLAR HEATING AND COOLING TECHNOLOGIES

The types of SHC technologies vary in accordance with their end-use application because thermal energy is needed at different temperatures and in different media (primarily air or water) and must be used near the point of generation. The following sections explain major SHC applications and technology requirements, provide detail on the most significant SHC components (primarily collectors), and give an overview of the current SHC performance and price estimates.

6.2.1 SOLAR HEATING AND COOLING APPLICATIONS

SHC historically has been associated with water heating, which is the third-largest end-use energy demand in the U.S. residential sector and the sixth largest in commercial buildings. However, SHC can also provide energy for space heating and cooling. This section highlights current and emerging SHC technologies, including domestic SWH, solar pool heating, active solar space heating, solar space cooling, and other SHC applications.

Domestic Solar Water Heating

Domestic SWH systems gather the sun's radiation and transfer heat to water in a storage tank, either directly or indirectly via a heat-transfer fluid such as propylene glycol. The tank can be a modified standard water heater or, more commonly, a larger and better-insulated unit designed for SWH systems because greater hot water demand typically occurs in the morning or late evening and does not match times of maximum solar radiation. A SWH system is normally supplemented with a conventional water heating system as backup.

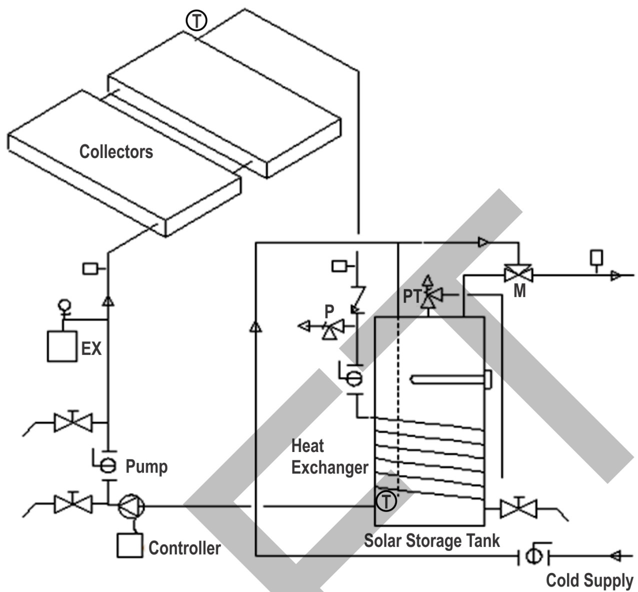
Domestic SWH systems typically use glazed or evacuated tube collectors (See section 6.2.2 for a description of collector types) and can be active or passive**.** Active SWH, which is more common in the United States, relies on electric pumps and controllers to circulate water or heat-transfer fluids through the collectors. There are two types of active systems:

Indirect forced circulation SWH uses pumps to circulate heat-transfer fluids through the solar collectors (Figure 6-1). Heat exchangers transfer the heat from the fluid to the domestic water supply. These types of systems are required in areas where freezing temperatures occur.

Direct forced circulation systems use a pump to circulate water directly through the collectors and into the storage tank for use in the building. These systems are not recommended for climates that experience freezing temperatures.

As with active systems, passive SWH systems can be direct or indirect. The two basic types of passive systems are integral collector-storage (ICS) systems and thermosiphon systems. ICS systems use building water pressure to move water through the collector. Thermosiphon systems allow water to circulate naturally as it is heated, rather than requiring mechanical pumps. Because passive systems have no electrical components, they are generally less expensive, more reliable and easier to maintain than are active systems. However, passive systems are usually most appropriate in climates that do not experience freezing temperatures.

Figure 6-1. Indirect Forced-Circulation SWH System

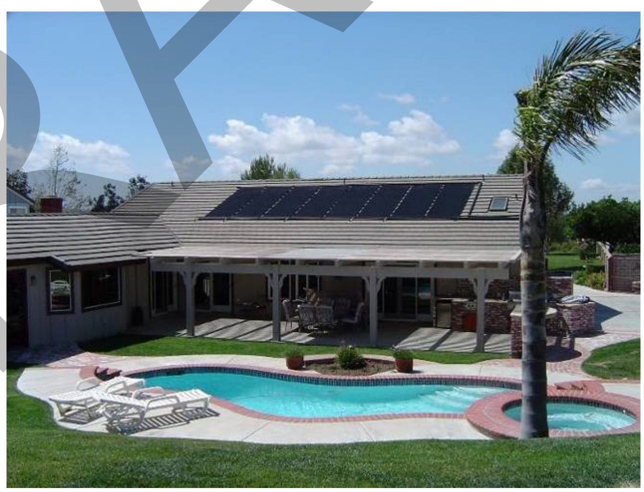


Solar Pool Heating

Solar pool heating is currently the largest use of SHC in the United States. It is used most often in homes, but hotels, municipal governments, and other commercial customers are starting to adopt it.

Solar pool heating systems typically use the existing pool-filtration system to pump water from the pool to a solar collector. The sun heats the water as it flows through the collector, and the heated water is returned directly back to the pool. Solar pool heating systems typically operate at temperatures near the surrounding air temperature and can therefore use unglazed flat-plate collectors. These low-temperature collectors are often made from polymers (Figure 6-2). Solar pool heaters can extend the swimming pool season by several months. Glazed flat-plate or evacuated tube collectors may also be used, usually for indoor pools, hot tubs, or spas in colder climates.

Figure 6-2. Polymer Solar Pool Collectors



(Photo courtesy of FAFCO)

Active Solar Space Heating

Active solar space heating systems for residential and commercial buildings use a solar collector to heat liquid or air, from which thermal energy is transferred either directly to an interior space or to a storage area for later use. Liquid-based hydronic heating systems are generally used when storage is required.

There are several types of active solar hydronic heating systems using glazed flat-plate or evacuated-tube collectors. In radiant-floor heating systems, heat is radiated from liquid flowing through pipes embedded in or suspended below a concrete or wooden floor. Flat-plate collectors can be used in these systems because they perform well at relatively low liquid temperatures (120°–140°F). Baseboard or radiator hydronic heating systems require higher liquid temperatures (160°–180°F); therefore, they use larger baseboard or radiator surface areas with flat-plate collectors or use higher temperature evacuated-tube collectors. For forced-air heating systems, a liquid-to-air heat exchanger is incorporated into the supply air duct from the furnace to transfer solar heat to the air.

Air-based solar heating systems use air for absorbing and transferring solar energy to provide direct space heating or preheat air captured in a ventilation system. The most common type of air-based systems for residential applications use flat-plate air heating collectors placed on the roof or south-facing wall of the building. Fans blow air from a room into the collector to be heated and then back into the room. Transpired collectors are an unglazed application of flat-plate collectors. These perforated collectors are located on the south face of a building and will preheat the air passing through them into a ventilation system. Because these systems work best with high ventilation loads, they generally are used only in larger, nonresidential spaces.

Liquid- and air-based systems can provide solar space and water heating simultaneously. These combination systems have electric pumps and heat exchangers that transfer and distribute heat. For example, when warm air is not needed, some air-based systems can employ an air-to-liquid heat exchanger to heat the domestic water supply.

Solar Space Cooling

Space cooling is the newest and least-developed building SHC application. Space cooling can be achieved using thermally activated cooling systems (TACS) fueled by solar energy. The TACS currently available for solar space cooling are absorption, adsorption and desiccant systems. These systems are generally only currently available at commercial or industrial sizes.

Absorption systems require solar collectors capable of achieving high temperatures, such as evacuated-tube and concentrating collectors, in order to separate a binary mixture of an absorbent and a refrigerant fluid. The refrigerant is condensed and eventually evaporates to produce a cooling effect. Absorption systems that use thermal energy from burning natural gas or other fossil fuels provided the first space cooling and refrigeration before the advent of electric vapor-compression cooling equipment. Absorption cooling still makes economic sense in some parts of the United States and is used extensively in Japan.

In desiccant systems, solar thermal energy can be used in the regeneration phase to dry desiccant material that has absorbed moisture in a latent cooling system. This type of system can work well in areas, such as the Southeastern United States, where humidity is high in the summer. Humidity is a key factor in space cooling; using solar energy to reduce humidity reduces the amount of conventional energy needed to cool the air.

Other SHC Applications

Large-scale industrial process solar heating and cooling have been deployed internationally and are beginning to develop a market presence in North America. According to the IEA, the following are the most promising applications of industrial SHC (Weiss et al. 2009):

- Cleaning, primarily in food processes, but also for process equipment and metal-treatment plants (galvanizing, anodizing, painting)
- Commercial laundries
- Car washes
- Drying requirements after cleaning in the food and chemical industries
- Pasteurization and sterilization for the food and biochemistry sectors
- Preheating of boiler feed water.

Figure 6-3. Concentrating Solar Collectors for District Hot Water System at a Federal Prison, Phoenix, AZ

(Photo courtesy of IST Abengoa)

Solar thermal systems designed to heat large quantities of water for nonresidential buildings and industrial processes may use many of the same systems (with modifications) as those used for domestic applications. Flat-plate collectors provide a good option for large volumes of relatively low-temperature hot water. Evacuated-tube and concentrating collectors are generally more applicable in large commercial and industrial applications, since they can achieve higher temperatures than flat-plate collectors. Two U.S. examples of solar process heating are a Frito-Lay plant in Modesto, California (concentrating collectors produce steam for heating oil used to make potato chips), and a Gatorade bottling plant in Tolleson, Arizona (large flat-plate collectors produce low-temperature hot water for product blending.).

Emerging agricultural uses of SHC include heating greenhouses, drying crops, providing hot water for dairies, and providing space heating for farm buildings. For example, a solar-assisted drying system at a Costa Rican coffee cooperative uses 850 m^2 of glazed, roof-mounted, flat-plate solar collectors to warm air that intake fans use to dry coffee beans.

In the United States and Canada, there is a growing market for unglazed air collectors (e.g., transpired collectors) for commercial and industrial building ventilation and heating as well as agricultural applications (Weiss et al. 2009). Process cooling represents a much smaller portion of process energy use, and solar process cooling is a relatively small and undeveloped market (IEA 2010). In the United States to date, most interest appears to be in wineries and food storage applications.

Another untapped market is use of solar thermal energy for district heating and cooling systems, which like industrial systems, are large, relatively complex, and rely on higher-temperature collectors. Steam/hot water or chilled water is provided from a central plant and piped into buildings (e.g., in a hospital complex or university campus) for domestic hot water, space heating, and/or space cooling. The U.S. federal and state governments have used solar collectors to provide bathing, cooking, laundry, and space heating for schools, military sites, office buildings, and prisons (Figure 6-3).

6.2.2 SOLAR COLLECTOR TECHNOLOGY

Collectors, which gather the sun's radiation, are a key element in all SHC applications. Types of solar collectors include flat-plate collectors, evacuated-tube collectors, integral collector-storage systems, transpired collectors, and concentrating collectors. The collectors that gather both direct and diffuse solar radiation are described in the following sections, followed by a basic review of concentrating collectors, which gather direct radiation only.

Flat-Plate Collectors

Most solar collectors used in the United States are flat-plate collectors, which are generally designed to heat a fluid (water or air) at temperatures not exceeding 180°F. The two primary types are glazed and unglazed flat-plate collectors.

Liquid flat-plate collectors heat liquid (usually water or an antifreeze solution such as glycol) as it flows through tubes in or adjacent to a dark-colored absorber plate. The absorber plate is typically covered with a coating that absorbs solar energy while inhibiting radiative heat loss. A glazed liquid flat-plate collector is covered with glass or translucent plastic to achieve higher temperatures (Figure 6-4). An unglazed liquid flat-plate collector is not covered and is therefore often used for lower-temperature applications, such as pool heating.

Air flat-plate collectors typically consist of a glazed, insulated metal box with a dark metal absorber plate. The sun heats the absorber plate, which heats the air in the collector. The air flows (by natural convection or fan) through the collector and across the absorber plate . Less heat is transferred between the air and the absorber than with a liquid flat-plate collector; however, air heating collectors can eliminate any concerns with freezing or boiling associated with liquid systems.

Figure 6-4. Glazed Flat-Plate Collector

(Photo courtesy of Rheem)

Common applications for flat-plate collectors include residential water heating, pool heating, residential space heating, and industrial process heat. Efficiency varies with collector design and application temperature, but typical overall efficiency for a liquid flat-plate collector is 40%–50% in their normal operating range.

Evacuated-Tubes Collectors

Evacuated-tube collectors can achieve temperatures of 170–350°F. There a variety of types of evacuated-tube collectors. One common type is designed with parallel rows of twin glass tubes, with each inner glass tube containing a metal tube attached to an absorber fin. The air between the two glass tubes is removed (or evacuated) to form a vacuum, which reduces conductive and convective heat loss. Common applications include residential and commercial water heating, space heating and cooling, and industrial and process heat. Efficiencies of 30%–45% are typical.

Integral Collector-Storage Systems

ICS systems preheat water before it goes to a conventional water heater. These systems generally use one or more tanks or tubes that act as both the solar collector and storage within an insulated glazed box. ICS systems are passive in design, using building water pressure to maintain water flow.

Transpired Air Collectors

Transpired air collector systems consist of dark, perforated metal plates installed on the south face of a building, with an air space between the building wall and the metal plate. An added fan or the existing ventilation system draws air through the perforations and into the air space between the collector and the building. Transpired air collectors do not require glazing and can warm the air by as much as 40°F. Common applications for transpired air collectors include commercial air heating and ventilation systems.

Concentrating Collectors

Concentrating collectors use mirrors or lenses over a large area to focus the sun's rays onto a smaller absorber (called a receiver). The major types of concentrating collectors are parabolic trough and linear Fresnel (see Chapter 5 for additional details on these types of collectors). Concentrating systems are most practical in areas with high direct solar insolation. Common SHC applications include district water heating systems, commercial space cooling systems, water purification, and industrial process heat.

Hybrid Collectors

Though still uncommon, there are combined photovoltaic/thermal (PV/T) collectors that incorporate PV electricity and thermal energy collection on the same equipment. Collecting both thermal and electric energy enables more efficient use of roof space and can increase total energy yield out of a system with potentially lower costs than separate stand-alone SHC and PV systems.

6.2.3 Performance and Price

The price of SHC technologies varies by application; in general they have been considered the most cost-competitive "active" solar technologies. Like other solar technologies, larger SHC systems are more cost effective than smaller systems because fixed costs (engineering, permitting, etc.) can be spread over a greater output. SHC systems that offer more than one type of application also can be more cost effective. For example, excess summertime energy from a SWH system could be used for space cooling, thus using more of the energy produced and lowering the per-unit energy cost. Similarly, a solar air heating collector could be adapted with an air-to-fluid exchanger to meet hot water needs during summer months when space heating is not required.

Domestic Solar Water Heating

Depending on the type of system it displaces, a typical residential SWH system saves 50%–80% of a conventional system's energy use, which is an average of 3,400 kWh of electricity or 17,000 cubic feet of natural gas annually in the U.S.. SWH currently displace about 13 trillion Btu in electricity and natural gas each year, which combined exceeds the annual residential natural gas use in Delaware (EIA 2009).

A typical residential SWH system produces 50–100 gallons of hot water per day and costs \$2,500–\$12,000 installed; a conventional gas or electric system costs \$600–\$1,350 (ACEEE 2006). The large cost range for SWH systems results from the variety of technology types available for different applications and climates. Evacuated-tube collectors can be twice as expensive as flat-plate collectors. ICS systems are the least expensive—and the simplest and most reliable—SWH systems, but they are vulnerable to freezing and perform best in warmer climates.

The simple payback period for residential SWH depends on the cost of the system, the cost of the energy saved, and the quality of the solar resource. Figure 6-5 shows the simple payback period of U.S. SWH systems using 2005 residential electric utility rates (without incentives). In the red areas of the map, a typical residential SWH system with 64 ft^2 of collector area has a simple payback of 1–10 years when system costs are less than \$5,400. Only in Hawaii and parts of Alaska, where electricity rates are high, are payback periods less than 5 years. In the orange areas, payback periods are 10–15 years (without incentives) (NREL 2005). SWH systems generally require incentives to be cost competitive in the United States.

Solar Pool Heating

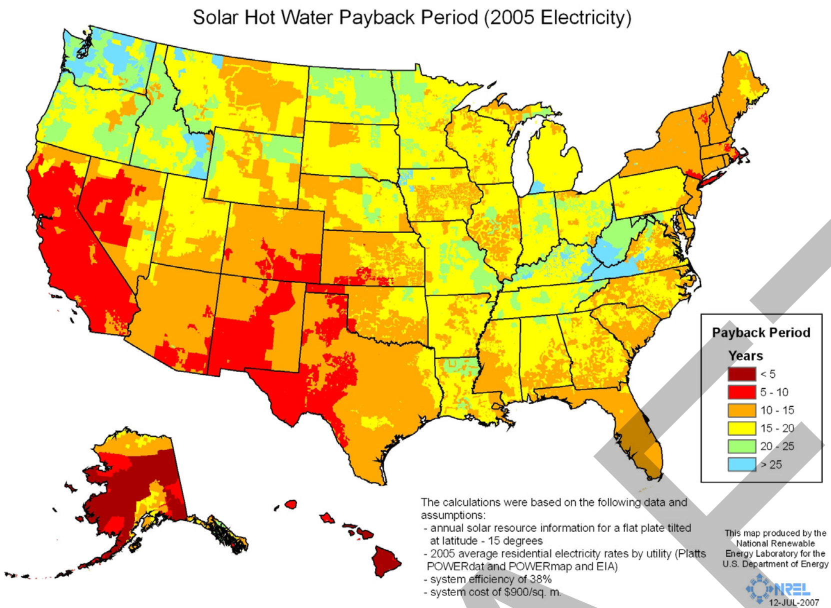
Solar pool heaters generally use unglazed flat-plate solar collectors that are 50%–100% of the surface area of the pool. The larger the system, the longer the pool season can last. The installed cost of a solar pool heating system ranges between \$2,000–\$10,000 (or \$7–\$12 per square foot) depending on the system type and size. The payback period is typically 1.5–7 years, depending on the cost of the competing system and/or energy source. Solar pool heaters require minimal maintenance and have a life expectancy of 10–20 years.

Active Solar Space Heating

Active solar heating systems are most cost effective when used in combination with other applications, such as SWH, and when they can be used for most of the year (i.e., in sunny climates). Commercial solar heating systems and their associated installation costs are \$30–\$80 per square foot of collector area. The collectors generally include warranties over 10 or more years.

Liquid-based hydronic solar space heating systems can store energy for later use and/or be used for other applications such as water heating. Air-based solar space heating systems produce heat earlier and later in the day than liquid systems and avoid the risk of freezing. Transpired air collectors for ventilation air are relatively inexpensive because they do not require glazing.

Figure 6-5. Residential Solar Water Heating Payback Periods without Incentives, 2005



Solar Space Cooling

Solar space cooling is not as common as SWH and space heating due to its high initial costs ($7,000–$20,000 per ton). It is estimated that there are approximately 20-30 solar space cooling systems operating in North America. (IEA Task 38, 2010) When combined with SWH and/or space heating, solar space cooling can become increasingly cost competitive, particularly for large commercial applications. Chillers that can operate using solar energy are generally more efficient at higher temperatures which favor the use of evacuated tube or concentrating collectors. However, some cooling systems (e.g. single effect absorption, adsorption, desiccant) can be driven using the lower temperature energy produced by flat plate collectors, which are generally lower in cost. When determining the optimum system for a given solar cooling application, many factors must be considered including collector mounting, appearance, total system cost, energy output and on-going operating costs.

6.3 Cost Reductions and Technology Improvement Opportunities

Some SHC applications, such as domestic SWH and solar pool heating, are mature. Performance and cost improvements over the past several decades can be attributed to the use of low-iron, tempered glass for glazing, improved insulation, and durable selective coatings. However, cost and technology improvement opportunities are still available for these mature applications through making systems more adaptable for retrofits, using lower-cost materials, installation cost reductions and through adoption in new construction that eliminates the added costs associated with retrofits. Emerging SHC applications could benefit even more from research and innovation.

6.3.1 Technology Improvements and Research Needs

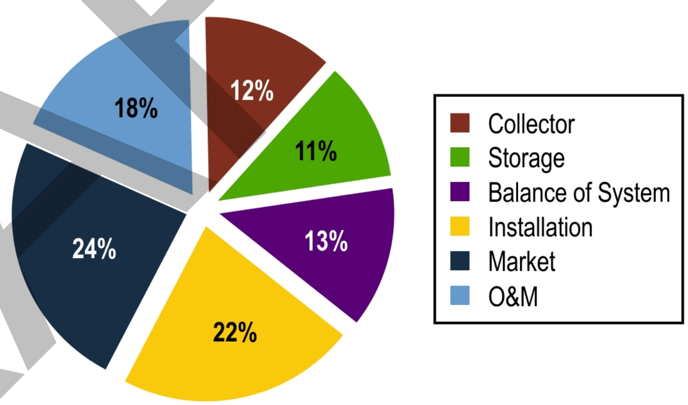
Technology improvement efforts for SHC focus on improving durability and reliability while reducing costs. Figure 6-6 shows a typical distribution of SWH component costs. The remainder of this section highlights key areas for technology improvement and cost reduction.

Solar Collectors

For flat-plate, an order of magnitude increase in production could bring down costs; today, many collector production lines are small, and products are built to order, resulting in higher costs. Replacing copper, glass, and aluminum with polymer or composite materials reduces material also could reduce costs as well as weight.

Producing commercial-specific collectors—which are larger and thus require fewer connections per unit of energy produced—could improve cost and performance. However, because many commercial systems must have proven high performance and longevity, the use of alternative materials in these systems may be delayed or even excluded.

Figure 6-6. Typical SWH System Component Costs



Technology improvements for storage, balance of system, and installation likely will be shared by flat-plate and evacuated-tube collectors. Concentrating collectors will benefit from some of the reflector and absorber improvements indentified for concentrating solar power (CSP) systems based on linear concentrators. See Chapter 5 for details on CSP systems.

Diurnal Thermal Storage

For active systems with storage separate from the collector, storage is a major cost component. Historically, most active systems have used pressurized storage. Using unpressurized storage could reduce costs, although a load-side heat exchanger with high effectiveness is then required. Unpressurized storage can be made from thin-wall polymer tanks (rotomolded or blow-molded) or from a membrane held in place by an external structure (e.g., cylindrical insulation plus metal or nylon sleeve). Enabling use of unpressurized storage will require developing and engineering design concepts, testing materials, building prototypes, and optimizing manufacturing.

Seasonal/Annual Thermal Storage

Water is the usual storage medium, but the ground beneath a building can also be used. Compared with SWH, solar space heating requires larger ratios of storage volume to collector area because energy must be stored for a longer time. Basic and applied research is needed for durable and cost-effective (plastic) liners and water-resistant insulation materials for long-term (seasonal) storage. The optimal storage size range must also be established.

Cooling and Refrigeration

Commercially available absorption, adsorption and desiccant systems are generally designed to use natural gas at temperatures higher than practical for flat-plate solar systems, and current low demand for solar products keeps prices high. However, absorption chillers designed to operate at temperatures more suitable for lower-cost solar systems are now under development in Europe and China. Liquid desiccant systems may become available that work well below 80^{o}C. For solar cooling to be commercially viable for residential applications, the technology must become widely available to enable cost reduction and standardization.

Balance of System and Controls

System control is more complex with combined heating and cooling systems. Interaction with heat-exchange fluid flow rates and interaction with heat-exchanger efficiencies and internal storage tank temperature stratification must be established. Depending on tank configuration, energy-distribution strategies must be optimized. Research is focusing on the collection, control, and distribution subsystems, excluding the thermal conversion machinery. Alternative control algorithms must be tested and optimized by simulation, followed by prototyping and testing. Commercial systems must also look to streamlined racking solutions, prebuilt pumping and mechanical gear, and other areas where field labor can be reduced or replaced by much more efficient labor in a factory environment.

System Integration

For building-integrated SHC systems, cost savings are possible via eliminating duplicate equipment and construction costs, reducing roofing materials, and increasing the life span of the conventional systems with which the solar collectors are integrated. For solar cooling, integration of solar collectors with the cooling equipment can lead to additional savings. Integrating heating and cooling systems mitigates summer overheating in SHC systems; the system can be used “full-out” all of the time and never needs to dump heat to prevent overheating-related damage. With annual storage, the overheating problem is eliminated. With diurnal storage, overheating may still occur on a sequence of moderate days when there is little cooling or heating needed. Basic and applied research is also required for the further development of large-scale solar collectors, the characterization of construction designs and plans for district heating solar energy storage, and the development of dedicated control devices and optimization strategies.

Reducing Margins

Small, independent contractors typically sell SHC systems one at a time. The marketing and sales costs per unit are therefore much higher than gas and electric water heaters sold through big-box retailers or plumbers and constitute a disproportionately large part of the total cost of an installed system (DOE 2006). Development of a more mature, higher-volume SHC market would help reduce these costs.

New Construction

Including SHC in new construction or making new buildings SHC-ready can eliminate duplicative engineering and construction costs associated with retrofits. Installing the appropriate piping eliminates the need for costly installation later on and choosing a solar-ready standard water heater can eliminate the opportunity cost of replacing an existing water heater when installing a SWH. Homebuilders could start building homes with SHC-integrated or SHC-ready homes. Alternately, building codes for new construction could be adapted to mandate SHC-ready homes as some states, e.g., Colorado, have done recently.

Manufacturing

Most manufacturers of specialized SHC components (collectors) in the U.S. run their factories significantly below capacity. Increasing the utilization rate of these factories will help the industry realized economies of scale by spreading out fixed costs across greater production. Greater production volumes would also enable greater automation, further lowering manufacturing costs.

Innovation

For an example of innovation as well as system integration, combined PV/thermal systems represent an opportunity to reduce the costs of both SHC and PV by consolidating the equipment, engineering and equipment expenses into one effort.

6.3.2 Risk Mitigation through Testing, Certification, and Performance Monitoring

SHC collectors and systems are tested throughout the world. Testing and certification in the U.S. is managed by the Solar Rating and Certification Corporation (SRCC), which specifies standardized tests for durability and performance for collectors and systems that qualify them for SRCC certification. The federal ITC, as well as most state and local incentive programs, require SRCC certification for collectors and systems. SRCC develops its test standards in consultation with other testing and certification bodies, particularly the International Standards Organization/Technical Committee 180 (ISO/TC-180) and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). The IEA is harmonizing testing standards between North America, Europe, and Australia to make it easier for manufacturers to qualify their systems for certification in each of these markets. Testing and certification are essential for protecting consumers from false performance claims.

The North American Board of Certified Energy Practitioners (NABCEP) operates testing and certification programs for solar system installers that provide similar assurances for consumers when selecting installers. As the SHC industry grows, monitoring of performance, aging, and reliability will be important for directing future research and product development and for validating accelerated aging tests for new materials and components such as polymers.

6.4 Materials, Manufacturing, and Labor Resources

In general, SHC technologies do not require exotic or rare materials, there are substitutes for many materials, and competing materials can serve similar applications. Manufacturing relies on equipment and techniques that are widespread in modern factories for handling glass, metal components, and polymers. In the United States, new SHC manufacturing could draw on experience in scale-up and automation gained by higher-volume manufacturers in other countries. The SHC labor pool can draw on workers with skill and experience from other manufacturing, engineering, and construction fields. The following sections discuss these considerations in more detail.

6.4.1 Raw Materials Requirements

For all SHC applications, the primary components are collectors, storage, and balance of systems components. This discussion breaks down the raw materials requirement by those categories.

Collectors

Collectors—made mostly of copper, aluminum, and glass—are the most materials-intensive components of a SHC system. The costs of these commodities have risen (and fallen) dramatically in recent years. Copper, for example, has ranged from a low of $0.76/lb in 2002 to $2.83/lb in March 2007 (USGS 2008). Developing substitutes such as polymers and designing to minimize copper use can reduce the impact of commodity price volatility and its effect on the capital costs of SHC systems.

Storage

Most SHC storage tanks are built with lined/coated steel or stainless steel. The technology is similar to that used for traditional water-heating vessels, for which there is no shortage of supply or competition, although commercial and industrial systems may require larger tanks than domestic systems. The larger the water storage tank, the longer the thermal supply can be considered a firm source of energy. Water is the most common storage medium, but advancements in phase-change materials could result in a shift away from water because these materials have the potential to store more heat in smaller vessels.

Balance of Systems

Balance of systems for SHC systems is primarily pumps, piping, and control systems. Copper (for piping) is by far the most prevalent material in balance of systems. The fluctuation in copper prices has led to more use of stainless steel pipe. Large commercial/industrial systems often use steel or stainless steel pipe owing to the lower cost for the larger-diameter pipe sizes found in those installations.

6.4.2 MANUFACTURING CAPABILITIES

In the United States, SHC manufacturing (except for solar pool heating) is far from optimal because markets have been vulnerable to fluctuations in policy and energy prices. Many SWH production lines rely heavily on hand assembly of components instead of automation and draw on off-the-shelf components from various suppliers who are unlikely to offer volume price reductions for SWH systems because the industry has too little demand to influence suppliers. Most U.S. manufacturing lines for SWH and solar pool heating are not at full production capacity and could respond to a surge in demand. Once this excess capacity is absorbed, industry would have to add manufacturing capacity and/or increase imports.

European countries, on the other hand, have stimulated manufacturing by promulgating long-term demand-side policies, resulting in more use of automation, greater influence over component suppliers, increased assembly and preparation of elements of the entire system on the factory floor (rather than relying on field adaptations), and a more diversified range of products. Production and use of evacuated-tube collectors is growing; the nature of the glass tube production favors high degrees of automation.

Industrial and agricultural applications that require concentrating collectors tend to be engineered on site. Manufacturing focuses more on an effective supply chain of component manufacturers for special glass (trough collectors), absorber/receivers, heat exchangers, and other components that are assembled at the point of use. This sector of the SHC industry should benefit from growing demand for CSP, because common trough and other concentrator designs for power production are not difficult to adapt to SHC.

For SWH storage tanks, manufacturing is likely to draw on the same manufacturing capabilities and production lines that now serve the overall water heating industry, supplying millions of water tanks per year. Existing manufacturers of polymer and metal underground and aboveground storage systems for chemicals and liquids would be the likely suppliers for more specialized storage components. The challenge for the SHC industry will be demonstrating enough demand and defining the necessary specifications and performance characteristics to interest suppliers.

6.4.3 LABOR RESOURCES

Labor is required for SHC manufacturing, design and installation, and operation and maintenance. The following sections discuss these areas.

Manufacturing

The types of labor required in SHC factory assembly vary with the type of product. Flat-plate collector manufacturing techniques involve the use of adhesives, welds, and fasteners followed by testing under pressurization and other quality tests. Evacuated-tube collector manufacturing is more focused on the glass tubes and receiver assemblies, specifically on ensuring a quality vacuum in the glass tubes and tube mounting connections in frame hardware. Higher-temperature concentrating systems that rely on trough or other concentrator designs require the manufacture of key components such as mirrors and receivers by specialty glass or component manufacturers using highly automated facilities. The actual systems are generally assembled in the field from components, although greater integration of components in a factory setting before shipment to the installation site is a promising avenue for reducing costs. Examples include streamlined racking solutions, prebuilt pumping and heat exchanger modules, and other areas where field labor can be reduced or replaced by factory assembly.

Design and Installation

SHC design requirements mimic those of most mechanical systems, and the scale of the SHC installation often dictates the source of design services. Although residential systems are often designed from components by senior installers or come prepackaged from manufacturers, commercial/industrial arrays usually require mechanical engineers. There is considerable HVAC and plumbing engineering expertise in the United States, but knowledge related to conventional water and space heating systems does not automatically translate to SHC systems, primarily because energy production from conventional systems is much more predictable than from SHC systems. Designing a SHC system that can anticipate and accommodate unpredictable energy production (and consumption) requires specialized design training for larger systems.

Residential and small commercial system installation requires expertise in roofing and plumbing, a combination of trade skills not typically found together in the construction workforce. Because of their weight, solar water heaters may require more labor and/or more equipment to install compared with conventional water heaters. In addition, some SWH systems must be assembled onsite, further raising installation labor costs compared with conventional water heaters. Finding and training licensed SHC contractors is a challenge in the limited, uncertain U.S. SHC market.

Large commercial and industrial systems require not only expertise in roofing and plumbing, but also in electrical systems. This expertise is more readily available within the commercial design and contracting arena as well as expertise in structural design for mounting large collector arrays. Some training is required for the specifics of each system and the solar interface with existing systems, but this training is normally provided by individual developers. Having access to workers who have training in thermal systems would help bring down the installation costs.

Operation and Maintenance

Although SHC system operation and maintenance is simple and relatively inexpensive, it may be one of the most important factors needed for a sustainable and growing SHC industry. Trained SHC technicians are the obvious choice for ongoing service, but the market dictates that many plumbers and mechanical contractors also will be required for the upkeep of SHC systems. Training and licensing are important. Many of the first modern solar systems installed in the 1970s and 1980s were often brought off-line owing to untrained professionals being called on for service, resulting in misdiagnosed problems that otherwise would have been fixed easily. There have also been examples of major systems remaining off-line owing to a single sensor, pump, or valve malfunction. The limited scale of the current SHC market is a problem for operation and maintenance because there is a lower concentration of systems in any one location, which increases travel costs involved in service.

6.5 REFERENCES

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