COGENRA SOLAR

Technical Advantages of Solar Cogeneration

Mitigating Stagnation Challenges Faced by Traditional Solar Hot Water Solutions

Executive Summary

Solar Hot Water (SHW) represents the most prevalent use of solar energy worldwide, exceeding photovoltaic (PV) energy production by roughly 500%. The installed capacity of SHW is growing at a rate of approximately 25% per year. However, two significant problems continue to hinder the adoption of SHW and suppress the industry's growth well below its full potential. The first challenge is economic, and stems from the fact that the economic value of thermal energy is relatively low compared to other forms of energy. SHW's returns are less attractive relative to other forms of renewable energy, despite the fact that the efficiency of SHW is relatively high, especially when compared to PV. The second challenge is technical, and relates to the possibility of SHW systems overheating and failing, a condition known as "stagnation", which therefore adds considerable complexity to their design and operation, which also makes SHW less attractive.

Cogenra's innovative solar cogeneration technology, the SunPack system, solves both of these problems, delivering faster financial payback and greater reliability than conventional SHW systems. Solar cogeneration integrates SHW and PV technologies into a single solar system that produces as much electricity per square foot as PV technology allows (~15% module efficiency) and captures a majority of the remainder of the sun's energy in the form of thermal energy (~60% efficiency).

Cogenra's solution allows customers to enjoy the best of both worlds: the high efficiency of SHW and the high economic value of solar PV. Another key advantage of Cogenra's solution is that it eliminates the possibility of stagnation, due to its tracking system, thereby considerably simplifying engineering requirements, operating protocols, and maintenance.

Overall, Cogenra's SunPack system delivers 200% the energy value of a conventional PV array and greater than 60% energy value compared to conventional SHW array.

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Overview of Solar Hot Water Market and Systems

While clean energy is a key theme in the climate change debate, most of the attention focuses on electricity generation and in the solar industry that typically means photovoltaic (PV) electricity. However, Solar Hot Water (SHW) represents the most prevalent use of solar energy worldwide, exceeding photovoltaic (PV) energy production by a factor of roughly 500% and is often overlooked by the industry. According to IEA, the newly installed capacity in 2009 was 36.5 GWth corresponding to over 560 million square feet of solar hot water collectors, which was an increase of approximately 25% from the previous year.

The SHW market is segmented into three broad classes of collector technologies:

1. Evacuated tube collector
2. Glazed flat plate collector
3. Unglazed flat plate collector

The first two categories dominate the worldwide market, while the third, unglazed flat plate collectors are simple, inexpensive modules that are most commonly used to heat swimming pools. Evacuated tube technologies have captured >55% of the worldwide market, led mainly by widespread residential adoption in China, where inexpensive tube manufacturing and low labor rates for maintenance make them competitive. Flat plate technologies, which account for a third of the worldwide market, are more suitable for commercial applications and are the dominant technologies in Europe and Japan[1]. In the recent years, flat plate SHW commercial installations are growing rapidly in the US at a rate of more than 20% in 2010.

However, there are two significant problems that hinder the adoption of SHW and suppress the industry's growth potential. The first challenge is economic, and stems from the fact that the economic value of thermal energy is relatively low compared to electrical energy. This makes SHW yield less attractive than other forms of renewable energy, like solar PV, even though the efficiency of SHW is relatively high (~60%), especially when compared to PV (~15%). The second challenge is technical and stems from the possibility of SHW systems overheating and failing, a condition known as "stagnation", which adds considerable complexity to their design and operation, making SHW less attractive.

[1] IEA. Solar Heat Worldwide 2011.

Stagnation

During summer months, when the thermal energy produced by solar collectors system is significantly greater than the energy used by a customer, the water temperature in the tank system rises and can rapidly reach the high-temperature limit of the SHW system. When this occurs, the heat transfer loop pumps automatically shut off to protect the tanks, pumps and other system components. This scenario is called stagnation, in which there is no flow through the system, while the collectors are still collecting thermal energy from the sun. The heat transfer medium (typically water-glycol solution) in the solar collectors can also reach extremely high temperatures during power failures, pump failures or times of minimal hot water consumption.

Virtually all fixed-tilt SHW systems are prone to stagnation. When flow circulation ceases, the collector temperature rises rapidly until it reaches the stagnation temperature, which depends on the system efficiency and design, and can climb to as high as 204°C (400°F). At these high temperatures, the water in the heat transfer fluid evaporates into steam, introducing a number of risks:

- Steam causes pressure in the system to rise. This pressure can be as high as 10 bar (150 psi) posing a serious safety concern.

- The combination of high temperature and pressure during stagnation severely stresses the collector loop plumbing, pumps, expansion tanks and heat exchangers, often resulting in leaks, pressure shocks, and system failures, thereby requiring frequent inspections and repairs. The high temperature causes the glycol and inhibitor additives in the heat transfer fluid to degrade, releasing glycolic acid which may damage the piping and components causing sediment buildup and scaling. This also destroys glycol’s freeze protection properties. As a result the glycol must be flushed out and replaced in shorter intervals, increasing operational maintenance costs.

Stagnation Mitigation Technologies

Several mitigation techniques are typically used by the SHW industry in order to protect the systems from the dangers of stagnation. The three main kinds are:

1. Pressure

In order to prevent the coolant from boiling, one industry practice is to increase the pressure in the entire solar loop. The higher pressure increases the boiling temperature of the water, but requires over-sizing or over-rating the system components to handle very high pressures, which adds to the cost of the system. Protection against pressure stagnation requires that the collectors and all other components in the solar collector loop be rated for pressures up to 10 bar (150 psi) and 204°C (400°F). Additional complexity is added via:

- Necessary use of high temperature high density (HD) glycol with an industrial corrosion inhibitor package. The HD glycol is not food grade and will therefore require a double-walled heat exchanger, a secondary pump and a pressurized storage tank, significantly increasing costs.

- Precise sizing of the expansion tank to control the pressure in the system to be above the vapor transition pressure. Over-sizing the tank will cause the fluid to steam during stagnation and under-sizing will result in blowing the pressure relief valve. Both scenarios incur increased operational and maintenance costs for frequent glycol inspection and replacement.

2. Drainback

In this stagnation mitigation method, to prevent the water from boiling, all the water in the collectors and exposed piping is drained into an insulated drainback reservoir tank when the pump shuts off. This solution requires a sufficient tilt of the collectors and the piping to allow for complete drainage. In addition, drainback systems require:

- A sufficient gradient of the collectors and piping to enable complete drainage. If there are any low spots, water may collect, preventing successful drainback. Installation and mounting complexity increase in correlation to increasing size of the collector array therefore making this solution impractical for commercial applications.

- An additional drainback tank, which for commercial applications adds to the installed cost of the system.

- That the solar collector loop operates at atmospheric pressure even in a closed-loop system. This increases make-up water maintenance requirements in order to recover daily evaporation losses and steam-off losses from stagnation. Therefore, glycol-based heat transfer fluids are typically not used in drainback systems and water is used instead, reducing freeze protection.

- The solar collector design incorporates parallel headers with risers since drainback of serpentine collectors is difficult, if not, impossible. Parallel flow collectors utilize higher diameter copper piping adding to the cost of the system.

- Due to design complexity, scalability is a challenge. For this reason, drainback systems are typically not used in commercial applications.

3. Steamback

In this mitigation methodology, the steam that forms when the water in the collectors boils, pushes the liquid glycol out of the collectors to protect the glycol from reaching high stagnation temperatures. Good collector designs for steamback protection reach temperatures up to 121°C (250°F) and pressures up to 10 bar (145 psi) during stagnation conditions. However, this technique also has the following challenges:

- During the emptying of the collector, the saturated steam becomes an efficient heat transfer agent from the collector to other components in the solar collector loop (heat exchanger, pumps, etc). This results in both high temperatures and pressure in the entire system, causing severe system stress.

- The emptying properties of the collector design determine the frequency, range, high-point and duration of the maximum temperature load of the systems and its components. Collectors with parallel header and risers have particularly poor emptying behavior while serpentine collectors perform better.

- The emptying behavior of individual collectors does not guarantee sufficient emptying of an array of collectors and is prone to problems when the collectors do not completely drain. This requires accurate system design, sizing and piping for each individual installation. Furthermore, even when working properly, the high temperatures reached at the boiling phase require that the heat transfer fluid be replaced relatively often, which increases operations and maintenance costs.

- Inhibitors are used in glycol-water solutions to protect the various collector materials from corrosion. During stagnation these non-evaporative inhibitors are deposited onto the collector tube walls. These inhibitors need to re-dissolve into the glycol-water solution when stagnation ends, and if not, then corrosion and collector tube blockage could result.

Other Stagnation Protection Techniques

An additional heat dissipater can be incorporated into systems to circulate the fluid. This is typically a relatively inexpensive engineering solution but requires electric power to run a separate pump which further increases operational costs. Another method is to implement an advanced controller that can circulate fluid through the collectors at night to dissipate the excess heat. This is an expensive option that increases capital costs and higher operational costs to run the pumps at night. Unfortunately, none of these precautions completely eliminate the risk of stagnation, and each new installation is typically custom designed by engineers with specialized expertise to account for the unique site dependent variables. In addition, the engineers designing the system must worry about both stagnation in summer and freezing in winter.

While the site requirements and constraints vary broadly, the challenge of avoiding stagnation creates several key technical disadvantages that broadly impact the SHW industry:

- All approaches to prevent stagnation in conventional SHW systems add a tremendous amount of complexity, and require significantly increasing the size and rating of the components or adding additional sub-systems, or both. The additional complexity increases installed cost and the number of potential points of failure.

- Each site is typically custom-designed, which inflates installed cost.

- Current approaches can mitigate the consequences of stagnation, but not completely eliminate it.

- Inspections and maintenance are required every time stagnation is suspected (and at least once a year) in order to test the integrity of the heat transfer fluid and to check for leaks, adding to operational and maintenance expenses.

Conventional SHW approaches are all prone to stagnation because their absorbers remain exposed to the sun in a fixed position constantly, meanwhile collecting heat while exposed to the sun. Solar cogeneration, which incorporates concentration and active tracking, intrinsically eliminates the possibility of stagnation. The result is simplified hydronic design, improved reliability, and lower system cost.

Cogenra SunPack System Overview

Concentrated solar cogeneration can be thought of as a concentrating SHW design in which silicon cells replace the usual black absorption coating. Silicon cells absorb solar radiation nearly as effectively as a black coating, but capture some of the energy as electricity and the remainder as heat, rather than all as heat. Alternatively, solar cogeneration can be thought of as a Concentrating PV (CPV) design in which water cools the cells, and the heat extracted from the cells is delivered as useful thermal energy rather than dissipated as waste heat.

In Cogenra's design, an array of mirrors concentrates sunlight from a wide collector area onto a narrow photovoltaic/thermal (PVT) receiver (Figure 1). Like any system that concentrates optical rays to a significant degree, Cogenra's system tracks the sun to keep the reflected light focused on the receiver. Tracking systems provide the additional benefit of effectively resolving SHW's stagnation problems. If the water temperature becomes too hot, the system controller automatically points the mirrors away from the sun, preventing further heating. Since the system generates its own electricity (PV), it can articulate the mirrors even if the grid power supply is interrupted or the circulating pump fails. This feature substantially narrows the range of water temperatures and pressures that the system must be able to handle, thereby dramatically reducing engineering requirements.

Each SunPack features multiple SunDeck® modules connected to Cogenra's iBOS™ unit, which combines an inverter, hydronics, and controller, enabling a plug-and-play installation process and full system solution. These packs can be linked together to

Figure 1: A single Cogenra SunDeck® module, which includes a collector area comprised of staggered flat mirror segments arranged in a parabolic arc and a PV/thermal receiver.

form a larger array with minimal custom engineering. Since the system generates its own electricity, it covers the parasitic losses associated with operating the pumps, trackers and electronics (conventional SHW systems require grid electricity). Integrated sensors and controllers direct all routine operations, detect problems that require maintenance, and alert the customer as needed.

Cogenra's system is the first to have received certifications for both PV and SHW, including OG-100 certification for meeting the durability, safety and thermal performance requirements of the Solar Rating and Certification Corporation (SRCC Standard 600) and International Electrotechnical Commission certification for CPV collector and assembly safety (IEC 62688).

Comparison to Conventional Technologies

Compared with conventional SHW technologies, Cogenra's approach offers several key technical benefits that result in economical advantages. The advantages and disadvantages of Cogenra's SunPack system relative to conventional collector technologies and other stagnation mitigation techniques are summarized in Tables 1 and 2.

	Drainback	Steamback	Pressure	Cogenra
Stagnation	Yes	Yes	Yes	No
Stagnation Temp / Pressure	170 F / 15 psi	250 F / 145 psi	400 F / 150psi	158 F / 30 psi
Freeze Protection	No	Yes	Yes	Yes
Glycol Replacement Interval	None	~2-3 years	~7 years	N/A; checked every 5 years
Heat Exchanger	Single-walled, coil type	Single-walled, coil type	Double-walled, external	Single-walled, coil type
Pump	Only in solar loop; Additional pump for drainback may be necessary if pressure head is high	Only in solar loop	Secondary pump needed	Only in solar loop
Tank	Non-pressurized	Non-pressurized	Pressurized tank	Non-pressurized
Expansion Tank	None	Large	Small but accurately sized	Small
Additional Tank	Large drainback tank	None	None	None
Collector Piping Configuration	High flow; Parallel headers	Low flow; Serpentine	High flow; Parallel headers	Simple design
Balance of System Piping	Copper	Copper	Copper	Copper / PEX
Gradient	1/4-inch per foot	None	None	None
Site Engineering	Significant	Significant	Significant	None

Table 1: Comparison of Cogenra vs. Conventional Stagnation Mitigation TechniquesConcentration and Tracking

	SHW		Cogenra SunDeck®
	Evacuated tube	Flat plate	Concentrating PVT
Advantages	• Relatively good performance in cold weather • Suited for high temperature applications > 60°C (140°F)	• Suited for low temperature applications · Glazed plates - up to 60°C (140ÐF) · Unglazed plates - up to 38°C (100ÐF)	• SHW + PV (2X energy value) • Strong performance in cold and hot weather • Zero risk of stagnation damages • Lower balance-of-system & installation costs • Plug and play design • Low maintenance / low OPEX • Parasitic losses covered by PV – no grid power required
Disadvantages	• High risk of stagnation damage • Highly customized engineering required for each new site • Frequent inspections / maintenance • Snow that collects on tubes may not melt and requires removal • Sensitive to incidence angle	• High risk of stagnation damage • Highly customized engineering required for each new site • Frequent inspections / maintenance • Efficiency decreases rapidly at weaker irradiation levels • Constant flow operation results in high parasitic losses (electricity must be supplied from the grid)	• 10-15% performance reduction in diffused light (common to all concentrating systems) • Tracker introduces moving parts (however, leveraging advances in PV tracking systems lowers overall system complexity)

Table 2: Technical advantages and disadvantages of Cogenra's approach compared with the leading conventional SHW technologies.

Concentration and Tracking

Cogeneration can be implemented with flat panels as well, but stagnation poses a significant risk to such panels. Moreover, concentrating the sun's rays onto a small form factor receiver yields additional advantages compared to flat-panel cogeneration. Since mirrors cost significantly less than silicon cells and water conduits, concentration delivers virtually the same amount of energy per installed area, at a much lower cost. It also simplifies the thermal isolation challenges that confront conventional SHW. Concentration and tracking also mitigate stagnation (overheating of the system caused when there is no flow) by de-tracking the receivers from the sun.

Cogeneration Synergies

Integrating PV and SHW into a concentrating solar cogeneration system leverages multiple synergies:

- Solar cogeneration extracts the maximum amount of solar energy per installed area of any solar energy technology.
- The PV and SHW share most of the cost elements, including the collector, tracker, balance of system components, installation, engineering and planning overhead, so the system can deliver far more energy value at a modest incremental cost.
- Concentration enhances the economics of PV by reducing the number of PV cells required and enhances the performance of SHW by reducing the area of thermal losses from the thermal absorber.
- The SHW conduits that collect the heat also cool the silicon PV cells, increasing their performance and eliminating the need for a separate heat dissipation sub-system.
- Tracking, which is rarely considered in SHW applications, increases energy yields for both PV and SHW, and eliminates SHW's stagnation challenges.

The combination of PV and SHW in one system optimizes the value of both at low incremental cost, since they share most of the same elements. Compared with PV alone, solar cogeneration delivers ~5X as much energy for a system of the same area, utilizing the same type of cells, because it captures and delivers the thermal energy that conventional PV dissipates as waste heat. More importantly, the total economic value of the energy that a solar cogeneration system delivers is more than twice as high as a PV system.

Solar cogeneration also has significant environmental benefits. By substituting electricity for some of the heat, solar cogeneration achieves at least a 30% greater reduction in Greenhouse Gas (GHG) emissions compared to a SHW system of the same size (same aperture, same tracking, and comparable cells).

Compared with a PV system of the same size, solar cogeneration achieves at least a 2.6X greater reduction in GHG because solar cogeneration yields more total energy output per area.

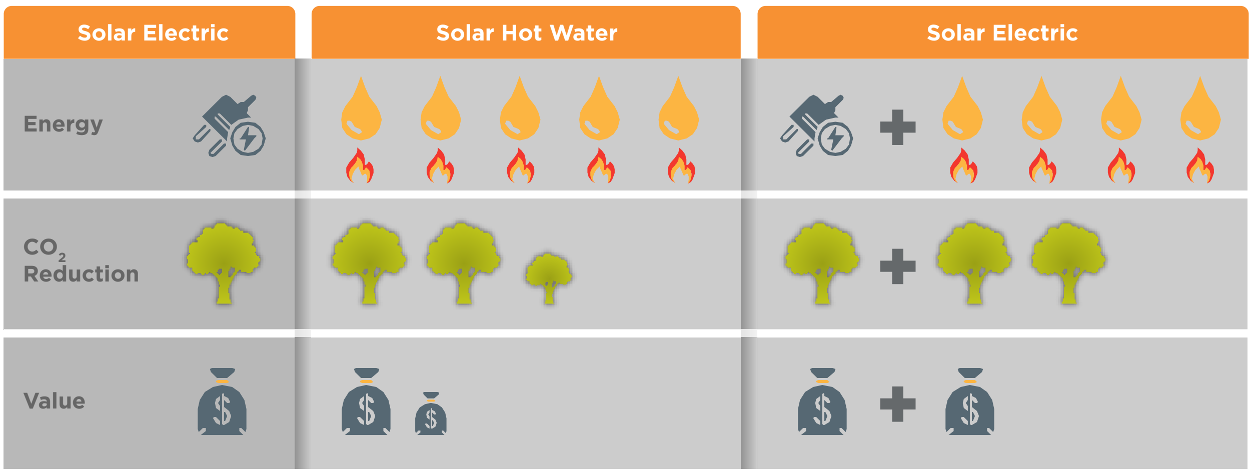

Figure 2: Solar cogeneration yields the most value from the sun over SHW or PV alone in terms of both economic and environmental benefits.

Conclusion

Solar cogeneration captures and converts up to 75% of the sun's incident energy into both electricity and hot water within a single solar array. The combination of photovoltaic and solar hot water technologies in one system makes solar cogeneration a cost-effective and environmentally beneficial solar energy solution for commercial and industrial-scale customers. In addition to the economic and environmental benefits, solar cogeneration also has significant technical advantages over conventional SHW due to its intrinsic solution to stagnation risk.

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