Technical Overview White Paper

Solar Cogeneration in Context

Executive Summary

Solar cogeneration captures and converts up to 80% of the sun's incident energy into both electricity *and* hot water within a *single* solar array. This integration of photovoltaic (PV) and solar hot water (SHW) technology into one system makes solar cogen by far the most cost-effective and environmentally beneficial solar energy solution available for commercial and industrial scale customers. Solar cogen extracts nearly twice the energy value per area under sun as conventional solar collection infrastructure. Since a comparable initial investment yields twice the financial return and can qualify for generous PV *and* SHW incentives, solar cogen can provide immediate savings to customers over utility rates. Solar cogen's environmental benefits are correspondingly greater.

Extended Summary

Ordinary photovoltaic (PV) systems convert only 15-20% of the sun's energy into electricity and struggle to dissipate the remaining heat energy into the air. Ordinary solar hot water (SHW) systems forego the opportunity to generate electricity, which often has 4X more economic value than natural gas (generally the least expensive fuel burned to heat water). Solar cogeneration of electricity and hot water maximizes the value of energy generated from the sun by producing electricity with standard PV technology and capturing remaining energy as hot water. Since a single concentrating solar collector unit can serve both functions, augmenting the PV receiver to transfer excess heat into water rather than dissipating it into the air adds very little additional cost to the overall system. Additionally, this modification allows the PV cells to run cooler which enhances their efficiency.

The thermodynamic advantages of exploiting PV+SHW together in solar cogeneration are similar to those of exploiting combined heat and power (CHP) in a conventional gas-fired cogeneration plant. CHP is more efficient than grid electricity because the heat of a CHP plant is utilized rather than wasted. However, such energy is not renewable power. CHP emits a wide range of air pollutants, which subject the owner to increasingly strict regulatory burdens and possible fines; these pollutants include nitric oxides, volatile organic compounds (VOCs), carbon monoxide, and will likely soon include carbon dioxide. Lastly, CHP operating costs are vulnerable to increasing natural gas prices.

Solar cogen surpasses CHP because it generates renewable energy, hedges volatile gas prices, and emits no pollutants.

Compared with a PV system of equivalent size, solar cogen can deliver up to 5X more renewable energy and nearly 2X more economic value:

1 electricity unit + 4 heat units (each worth 25% as much as electricity) = 2 value units.

By delivering all this extra energy value at low incremental cost, solar cogen is much more cost effective than PV or SHW alone. In California and Arizona, solar cogeneration qualifies for generous PV *and* SHW incentives. Combining these dual state incentives, federal tax incentives (available through 2010 as cash grants), and the 2-for-1 advantage in delivered energy value, an investment in solar cogeneration can pay for itself in full in less than half the time of PV or SHW alone. For its remaining 25+ year life, the solar cogen system effectively provides free electricity and hot water and insulates the owner from rising electricity and gas tariffs. The return on investment calculation may be even greater when considering the extra financial value implicit in this hedge, which is considerable given the high probability both that carbon legislation will be enacted and that demand will grow faster than supply over the next three decades. Additionally, third-party ownership options, such as Heat and Power Purchase Agreements (HPPAs), provide alternative means for end customers to benefit from immediate and long-term energy savings without the upfront expense or ongoing maintenance burdens.

In addition to these financial advantages, solar cogeneration reduces greenhouse gas (GHG) emissions 2.6X compared with PV alone and 1.3X compared with SHW alone. The advantages in terms of VOC and NOx emissions are comparable.

Table of Contents

Technical Overview: solar cogeneration in context

Photovoltaic systems (PV)

Photovoltaic systems (including solar cogen as a special class) all rely on semiconductor cells, arranged and encapsulated within modules that convert incident sunlight into electricity. Conversion efficiency from sunlight into DC electricity varies depending on the type of cell:

- Modules based on silicon cells, the most common type, typically range from 15% for multi-crystalline silicon to 20% for the more expensive mono-crystalline variety.
- High end mono-crystalline modules are expected to approach 25% over the next few years but will command a very high price.
- Exotic multi-junction devices made from compound semiconductors can exceed 40% but are so expensive that they have so far found practical application only in satellites.
- Thin film devices offer lower efficiencies, 6-12%, at lower cost, but the balance of system, engineering, and installation costs negate the savings in most scenarios.

The cells absorb as heat the remaining 75-95% of the incident sunlight that they cannot convert into electricity. This heat raises the temperature of the cells, which causes their efficiency to drop.

Most PV systems struggle to dissipate the excess heat. Solar cogen solves this problem by exploiting rather than discarding the heat. The process of transferring away the heat simultaneously cools the cells, enhancing their performance.

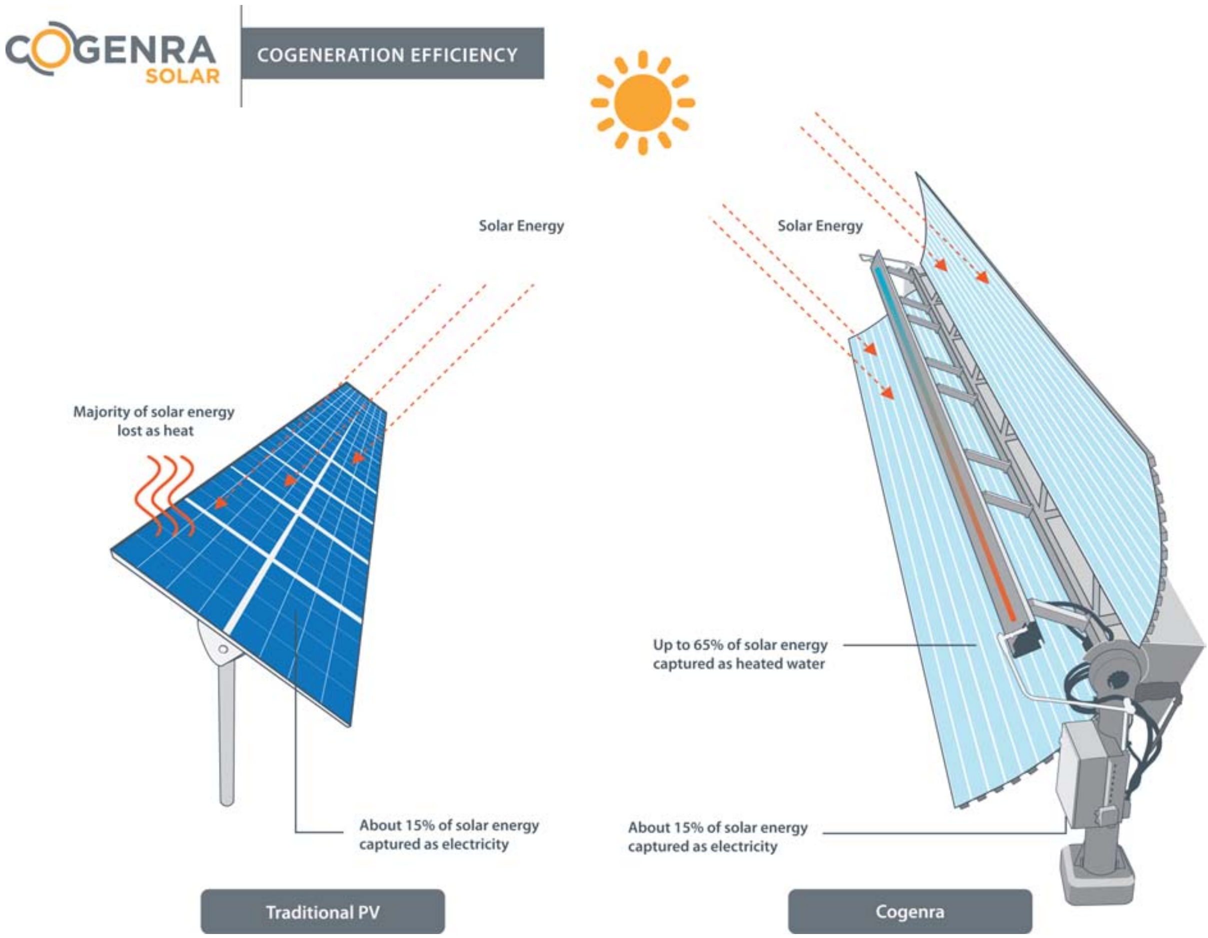

Figure 1: *Cogeneration Captures 5x Energy of Typical PV*

PV systems span a wide range of configurations:

- Fixed tilt — The simplest type of PV system is a series of flat panels mounted in a fixed orientation and at a fixed angle. This is the only type of system that can be easily installed on a tilted roof and is common in the residential sector.
- 1-axis tracked — Most new ground-mounted flat panels are installed on mounts that track the sun throughout the day. Compared with a fixed panel, a panel that rotates around a single axis (typically tracking from east to west) delivers 35% more total energy averaged over a year, more than justifying the cost of the tracking system.
- 2-axis tracked — Adding a second axis to track the inclination of the sun marginally improves energy capture vs. one-axis tracking and it rarely justifies the added cost.

Tracked systems also deliver a more level energy profile over the day compared with fixed position systems, whose outputs peak sharply at local noon. Filling in the shoulders in the energy delivery curve not only increases the total energy generated but also enhances the overlap with variable time-of-use (TOU) tariffs, whose peak value periods are typically centered in mid-afternoon rather than local noon.

Concentrating photovoltaic systems (CPV)

In a concentrating photovoltaic system (CPV), mirrors or lenses focus light from a wide collection area onto smaller PV elements. Mirrors and lenses are generally much less expensive than PV cells, which in principle enables a much lower cost per watt. All CPV systems with a significant degree of concentration (2:1 and higher) must track the sun to focus light onto the PV receiver. CPV is often broken up into three different regimes for discussion:

- At low concentrations (less than about 3:1), the savings on cells do not offset the cost associated with assembling the concentrators. These approaches have not fared well.
- At high concentrations (50:1 and higher), the complexity of assembling and aligning all the elements to high precision and removing the enormous amount of heat dumped onto small cells similarly outweighs the cost advantages. Accurate two-axis tracking is essential. Demonstration systems in this segment have encountered significant problems and delays.
- At intermediate concentrations, the sweet spot, the manufacturing tolerances and thermal issues are still easily managed, so CPV can achieve a slight cost advantage over PV in climates (such as most of California and the southwest US) where sunlight is mostly direct rather than diffuse. One-axis tracking with relaxed tolerances is sufficient.

One of the biggest challenges in a CPV system is keeping the PV receiver from getting too hot, since focusing all the light onto a relatively small area means that all the unconverted solar energy is similarly absorbed as heat in the same small area. Efficiency drops by 1% (e.g. 20% to 19.8%) for every 2° C that the temperature of silicon cells rise (effect shown in figure below). Even with no concentration, the temperature of a flat panel module can rise by 30-50° C under the mid-day summer sun. CPV systems require significant passive cooling (e.g. big cooling fins), or active cooling, or they will fail to work altogether. The expense of the cooling system offsets a large fraction of the savings from having fewer cells.

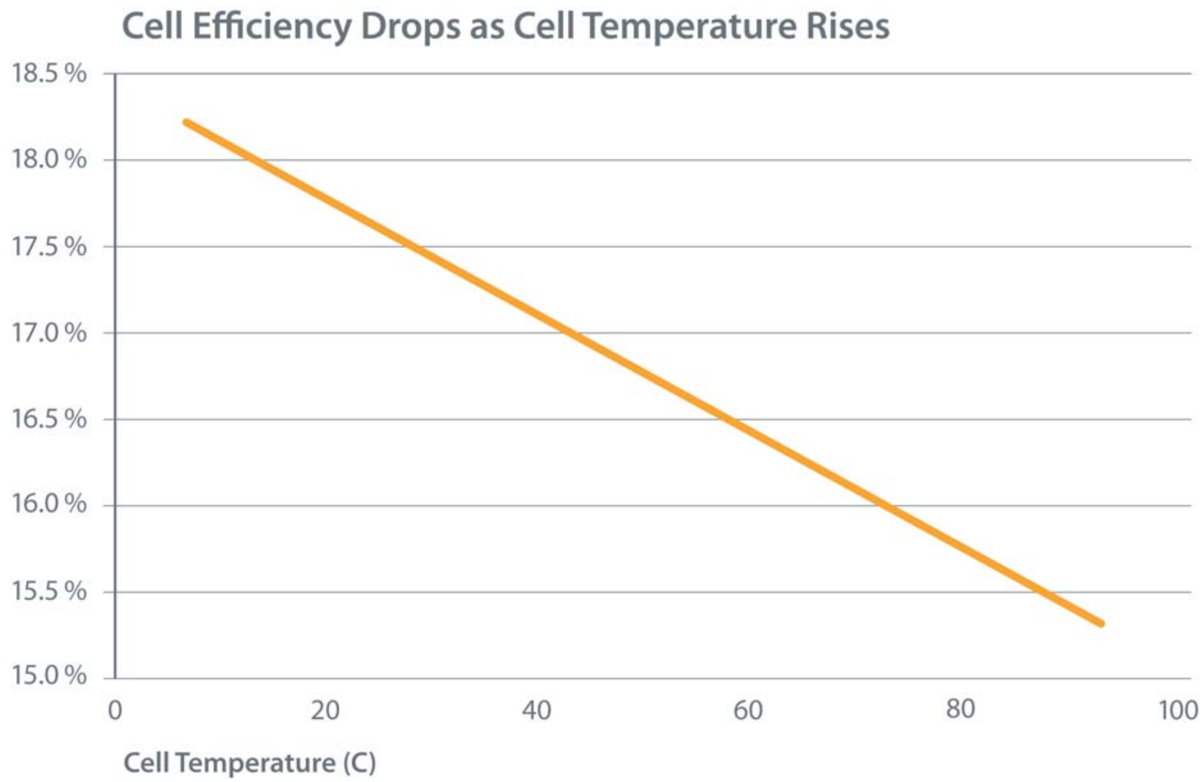

Figure 2. *PV Cell Efficiency versus Temperature (for a nominal 15-17% efficiency cell)*

Solar cogeneration

Solar cogen transforms the need for cooling from a liability (waste heat that must be ejected) into an asset (valuable heat that can be captured and exploited). Consider an intermediate CPV system that needs a cooling sub-system anyway and already has a slight cost advantage over PV in many regions of the world, even when the heat is dissipated. If the cooling system is connected to convey the heat as hot water to a customer who would otherwise burn natural gas or propane or use electricity to heat water, then the economics improve tremendously since the heat is nearly free. And there's a lot of it: even with 20% efficient cells, the amount of heat energy captured exceeds the electrical energy generated by ~3.8X. Solar cogen is simply an intermediate CPV system in which the heat is captured and delivered rather than dissipated.

Alternatively, solar cogen 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. The difference is that silicon cells capture some of the energy as electricity and all the remainder as heat. Trapping the heat does not pose the same thermal insolation challenges found in conventional SHW because solar cogen concentrates sunlight from a wide collector area into narrow receivers.

At California commercial utility rates, solar cogen systems deliver nearly twice the economic savings as a comparably sized CPV or PV system. Integrating the hot water into the customer's water systems does add further cost, which can amount to as much as 20% of total installed system cost. After accounting for these costs and their associated efficiency factors in careful detail, solar cogen still produces 50% more net energy value compared with PV/CPV per dollar of total installed cost. This makes it by far the most cost-effective solar technology available for commercial and industrial customers.

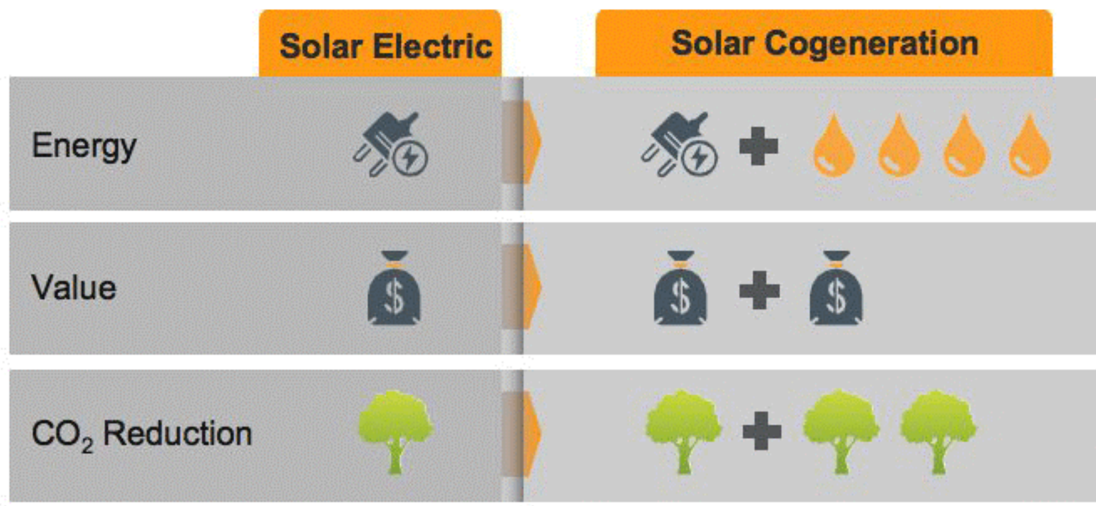

Figure 3. *Solar cogeneration generates 2x value and triples the GHG reduction over PV*

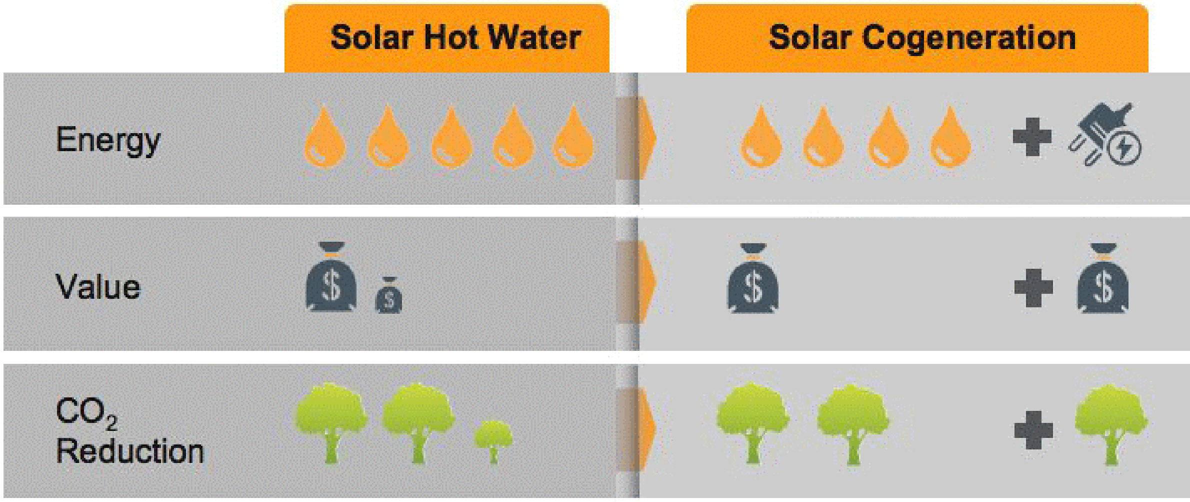

Figure 4. *Solar cogeneration generates 60% more value and higher GHG reduction than SHW*

Unleashing the value of the total delivered energy dramatically changes the economics of solar power much faster than striving only to push down the cost. Solar cogen can also leverage all the complementary ongoing advances in PV. As PV cells, modules, manufacturing techniques and inverters improve in performance and decline in cost year over year, new solar cogen systems benefit in lockstep.

Of course, solar cogen makes sense only when sited next to a facility that has applications for hot water. Electricity can be transmitted long distances over the grid with moderate losses, but hot water must be consumed locally. Figures 5 and 6 show some typical hot water applications:

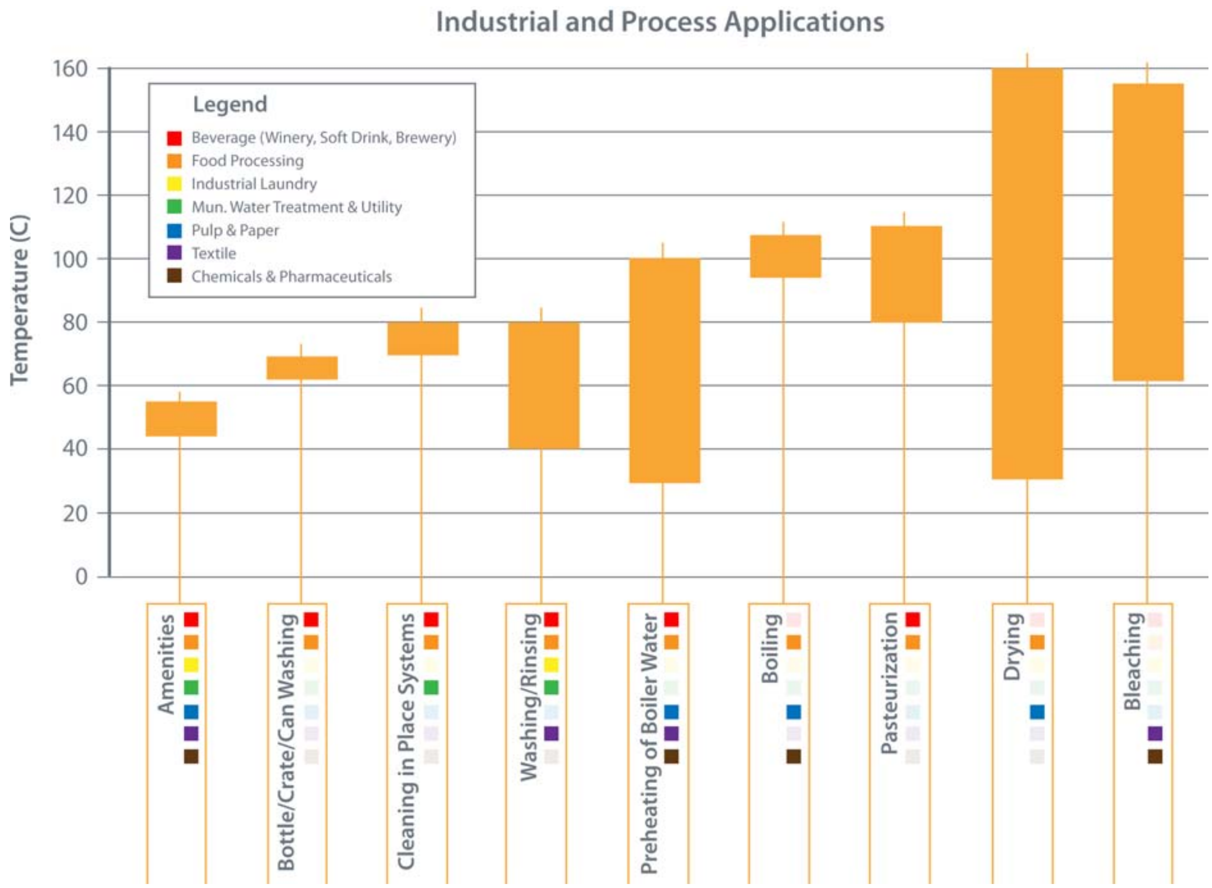

Figure 5: *Cogeneration Industrial and Process Applications*

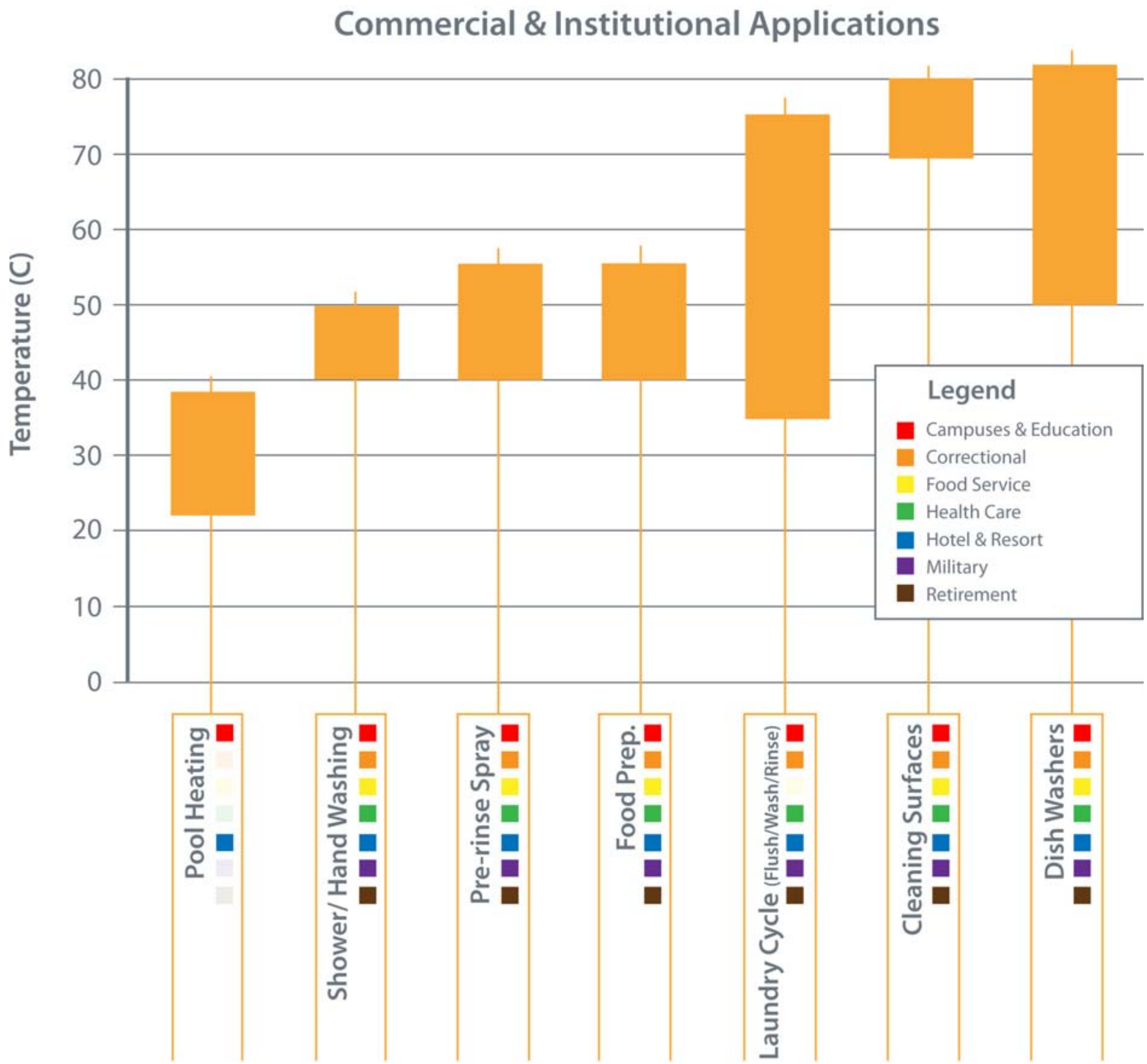

Figure 6: *Cogeneration Commercial and Institutional Applications*

For a utility-scale project in the middle of the desert, solar cogen offers no advantage. For commercial and industrial customers that need anywhere from 100,000 kWh of electricity and 25,000 therms of heat per year and higher, solar cogen offers economics better than any available utility rates. Figure 7 shows how a site would typically integrate the hot water and electricity produced through solar cogeneration. Electricity is net metered with the grid (same as standard PV) and hot water is fed to the boiler to reduce the amount of fuel consumed.

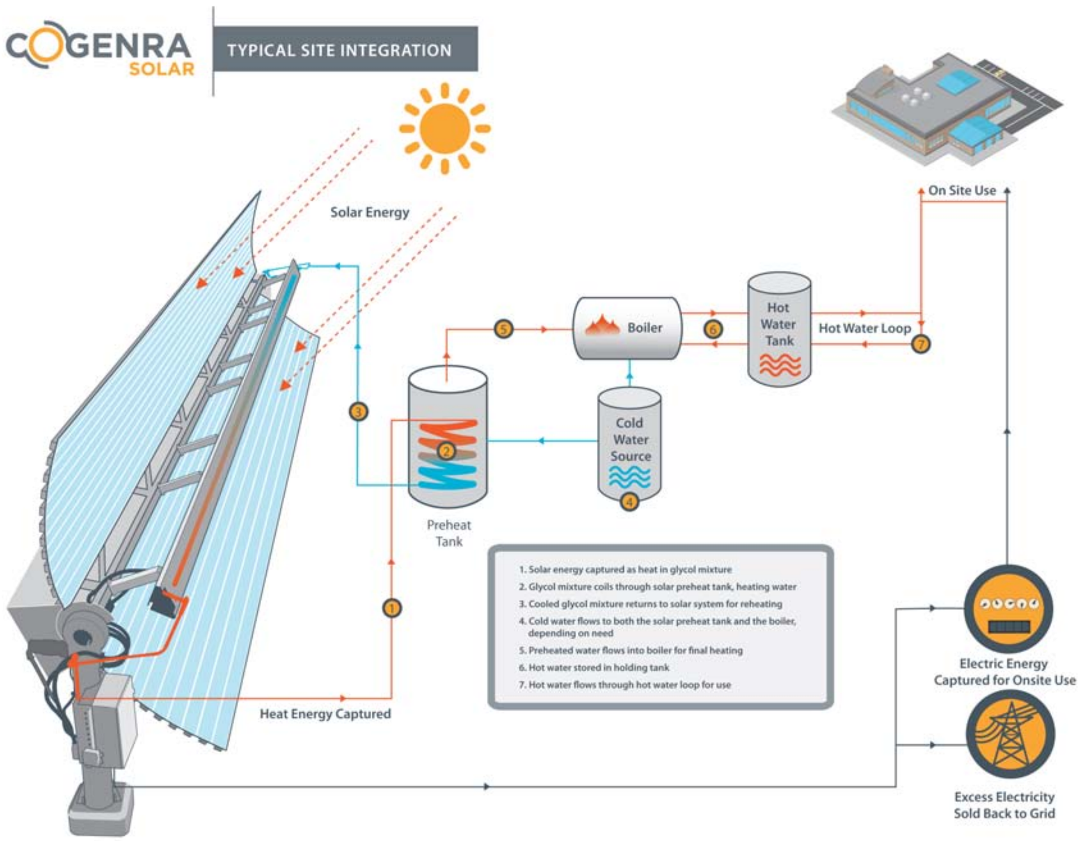

Figure 7. *Typical Site Integration*

Concentrating solar thermal (CST)

Solar cogen should not be confused with concentrating solar thermal (CST), which are utility scale systems that heat water, usually to 250°C or higher, in order to produce electricity with turbines. CST is sometimes called concentrating solar power (CSP), though technically CSP includes both CST and CPV. Although in principle a CST system could be located near a customer that could utilize its waste heat, in practice the large scales involved make this impractical.

Also, many CST designs waste water by not fully recycling the water that drives the turbines. Solar cogen systems neither consume nor waste any water; they heat water that the customer is already consuming.

Gas-fired cogeneration

Solar cogeneration derives its name from ordinary cogeneration, also called combined heat and power (CHP). Conventional power plants burn fuel to generate steam, drive turbines, and generate electricity. Very high efficiency turbines reach 40%. The rest of the heat is exhausted as waste. A CHP plant captures the excess heat and delivers it to nearby customers. Solar cogen is similar, except the sun is the source of energy instead of fossil fuel, and PV cells substitute for the generator.

Low-maintenance natural gas engine and natural gas turbine CHP units are now available in small “microCHP” sizes. These are suitable for commercial energy customers to install on their property, ranging from 10 kW to MWs. Though not as efficient at generating electricity as utility-scale units, their overall efficiency is higher than the grid when including capture of heat, and they can be more cost effective than utility rates.

Compared with solar cogeneration, however, gas-fired cogeneration has several disadvantages:

- Gas-fired cogen/CHP is **not** a form of renewable power. It is correctly touted as being more efficient than the grid — according to the Environmental Protection Agency’s *Combined Heat and Power Partnership* report, CHP systems typically consume 25% less fossil fuel than separate heat and power systems require. Solar cogen is fully renewable power: it consumes no fossil fuel.
- CHP operating costs fluctuate with the price of fuel. Historically, natural gas prices have risen much faster than electricity rates and have exhibited far higher volatility. Gas-fired cogen exposes the owner to substantial price risks, which could potentially result in a negative return on investment in the CHP unit. The high capital cost locks the owner into bearing these uncertain costs. Solar cogen insulates the owner from future fuel rate increases. The minimum return on investment is predictable, and the ROI increases as utility rates for gas and electricity increase.
- Gas-fired cogen units often emit an unpleasant odor, face permitting challenges, and entice opposition from neighbors. Solar cogen avoids these issues.
- Gas-fired cogen emits criteria pollutants (such as VOC, CO and NOx) that can incur regulatory burdens and fines in some districts. Solar cogen emits no pollutants.

Solar Hot Water (SHW)

At the other end of the spectrum are simple solar hot water (SHW) systems that do not attempt to generate electricity. SHW by itself makes sense for small residential customers who cannot effectively arbitrage differences in energy value. In a commercial and industrial context, solar cogen is far more cost-effective, because electricity has much higher financial value than natural gas. This is true even for flat rate tariffs. When TOU tariffs are considered, the logic of generating electricity becomes overwhelming. Net metering enables a solar cogen system owner to sell any surplus electricity generated during periods of peak demand back to the grid, when the TOU rate can be several times the average rate, and thereby offset substantially larger energy draws during the rest of the year.

Economic Advantages

For definiteness, this section focuses primarily on the California market. Other scenarios are also discussed qualitatively toward the end.

Utility rates in context

Salient points about commercial utility rates in California:

- Average commercial electricity rate in CA in 2009: $0.121/kWh
- Average commercial natural gas rate in CA in 2009: $0.025/kWh ($0.746/therm)
- On average, electricity is 3.7X more valuable than natural gas in CA at commercial retail rates. At the margin, under TOU tariffs above $.45/kWh, this ratio can exceed 10X.
- Utility rates enter into return on investment (ROI) calculations of renewable energy projects since, for example, solar cogen displaces consumption of electricity and natural gas that would otherwise be procured at commercial rates from the utility company. The value of the avoided utility consumption plus incentives offsets the cost of the investment plus interest (if financed) and maintenance.
- Electricity rates have risen 650% and natural gas rates have risen 1360% in California since 1970. Over the same period, the consumer price index (CPI) increased 430%. On an annualized basis, electricity outpaced inflation by 1% per year while natural gas ran ahead by 3%.

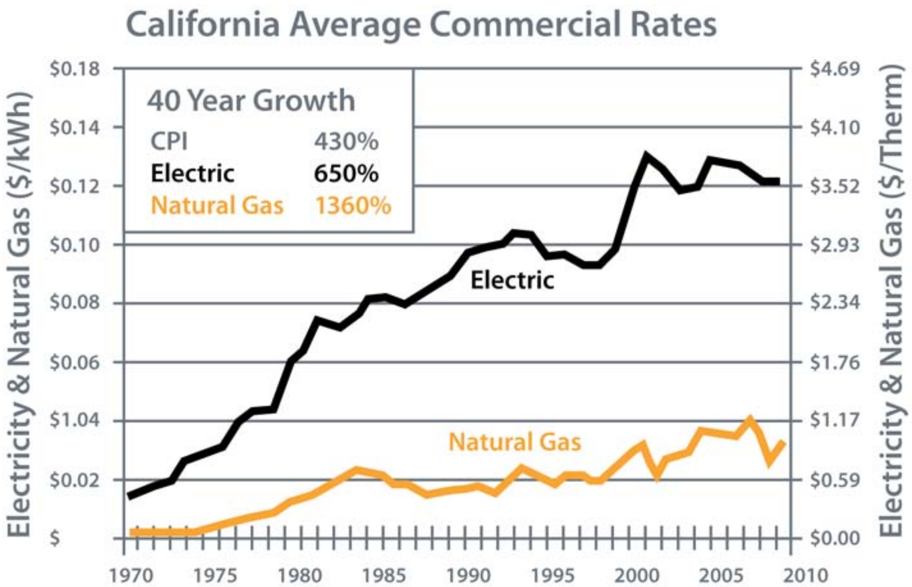

Figure 8. *Average California Commercial Rates*

- When a solar cogen system is properly sized to the customer's consumption and matched to the most appropriate available TOU tariff with net metering, the effective electricity rate that enters the ROI calculation can be significantly higher than either the average commercial rate or the customer's actual current marginal rate.

Incentives

Several different types of incentives are available for new solar cogen installations, and *they are cumulative*:

- The federal investment tax credit (ITC) rebates 30% of the total installation cost in the year the system is completed. The ITC is available as a credit against tax liabilities through 2016. However, for systems for which construction is started before the end of 2010, the credit can be taken as a cash grant from the US Treasury, even if no tax liability is owed. In addition, MACRS 5-year accelerated depreciation can be applied.
- The California Solar Initiative (CSI) offers a performance-based incentive (PBI) for new PV installations. The PBI provides a fixed monthly stream of payments for five years upon commissioning of the system. The payments depend on the amount of electricity generated and an incentive rate. The incentive rate offered to new systems

declines in steps that are triggered as more solar power is installed throughout the state, but the rate is locked in for a given system when it is approved to receive the incentive. As of August 2010, the incentive rate is $0.09/kWh for commercial customers in most of the state. New systems can still lock in this rate before the incentive drops to $0.05/kWh.

- A CSI-Thermal program was recently approved with a similar step rate structure, except in the case of SHW the incentive is paid out upfront based on the system capacity. The incentive rate begins at $12.82/therm ($0.44/kWh) of annual capacity, and the payment is capped at $500,000.
- Solar cogen simultaneously qualifies for all three of the above incentives. PV or SHW alone qualify for two.
- There is a window of opportunity to lock in the higher California incentives before the PV and SHW programs move down to their next steps. There is also a window of opportunity before the end of the year to take the federal ITC credit as a cash grant rather than a credit against tax liabilities.

Return on investment scenarios

Solar cogen can achieve full payback of the initial investment in half the time of any other solar energy technology.

- The return on investment depends on a myriad of factors that vary from site to site, including location, applicable local tariffs, current incentive step levels (in California), financing structure and interest rate, and total installed system cost. ROI also depends on projected future increases in avoided utility rates.
- When comparing ROIs for different technologies, it is important to control the technology-independent assumptions for a consistent comparison.
- For sites that consume both electricity and hot water, solar cogen will always offer a significantly higher ROI and faster payback than any other solar technology — PV or SHW — because solar cogen delivers significantly more energy and the highest possible value mix of energy types for the same investment. This fundamental advantage is insensitive to the specific assumptions in the financial model, so long as they are applied uniformly across technologies.
- In many scenarios where a traditional PV installation yields a payback of 10-20 years, solar cogen can achieve 4-7 years.
- These models assume flat utility tariff structures; they do not attempt to incorporate the benefits of TOU tariffs and net metering, which must be assessed case by case,

but will always increase the ROI and accelerate the payback if the system is planned properly.

- The ROI of gas-fired cogen (CHP) is far more sensitive than solar cogen to assumptions about future natural gas prices, since CHP actually consumes gas over the life of the system while solar cogen displaces gas consumption. Investing in CHP is a bet that gas prices will remain steady. Gas prices fluctuate with the market rate and have historically been volatile. Electricity tariffs are regulated. CHP shifts electricity costs off of regulated tariffs onto volatile gas rates and thus is highly exposed to potential spikes in gas rates. Solar cogen, in contrast, hedges against increasing gas rates.

Environmental Advantages

Greenhouse gas reduction

By generating more energy from the same infrastructure, solar cogen reduces more greenhouse gas (GHG) emissions than PV or SHW alone.

- 2.6X reduction compared with a PV or CPV system of the same size (same aperture, same tracking, and comparable cells).
- 1.3X reduction compared with a sophisticated SHW system of the same size (same aperture and same tracking). SHW systems do not generally track the sun, so solar cogen's advantage in practice is higher than this.

Other pollutants

Solar cogen offers similar advantages over competing technologies in terms of reducing air pollutants other than carbon dioxide — including volatile organic compounds, nitrogen oxides, sulfur dioxide, carbon monoxide and particulate matter — both locally and averaged across the grid. The absolute and relative reductions depend on the mix of generating sources in the regional grid.

Solar cogen also eliminates local emissions of pollutants compared with burning natural gas (either to heat water in boilers or generate electricity and heat water with CHP). In some air quality districts, elimination or avoidance of VOC and NOx can obviate regulatory burdens and eliminate fines.

Why Solar Cogen

Solar cogen is the most efficient solar power technology. It offers by far the fastest payback and cleanest environmental profile available to commercial and industrial customers.

Why hasn't solar cogeneration received more media attention? It primarily targets a handful of specific commercial, industrial, and government applications that consume a lot of energy but are not high profile, and only a handful of companies in the world offer solar cogen systems. Cogenra Solar is perhaps the only company that has designed a solar cogen array that provides PV and SHW at a cost no greater than a conventional PV array, fully exploiting solar cogen's potential to offer unrivaled return on investment and fast payback.

Contact

Cogenra Solar, Inc.
365 East Middlefield Road
Mountain View, CA 94043
info@cogenra.com
+1 650.230.3400