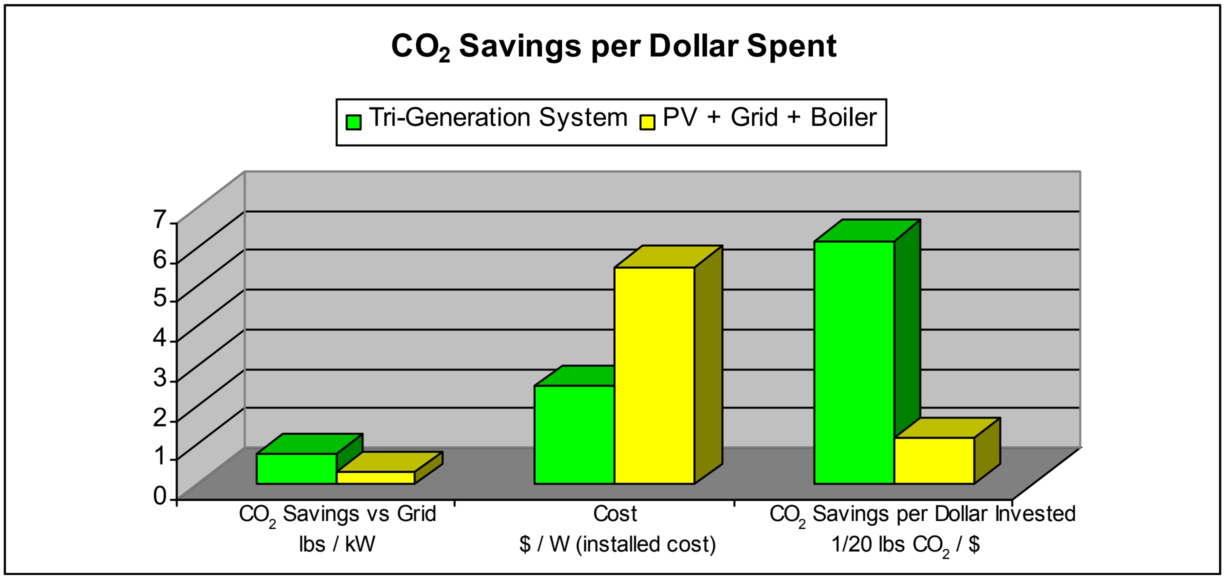
Natural Gas Tri-Generation Systems Emit Less CO_2 than Solar PV + Grid

Tri-Generation Systems Are Also 600% More Effective per Dollar Spent

The United States is blessed with an abundance of natural gas, coal, and solar energy. We are also the world's second highest producer of carbon dioxide emissions. The desire to reduce carbon dioxide emissions has persuaded federal and state governments to provide partial funding of solar power systems while discouraging coal consumption. Natural gas, however, has been promoted by some and discouraged by others. This paper will show that a facility using a properly sized tri-generation system burning natural gas will likely emit 25% less CO_2 per year than a traditional building using supplemental solar PV power.



First of all, solar cells obviously emit no CO_2 while operating. Instead, the emissions arise from the grid when solar power is not available. Coal-fired power plants are still the most common power source at most utilities.[1] These power plants are located away from urban areas. So the utilities are not able to harness the abundant exhaust energy created by combustion. Instead, those precious BTU's are simply released to the atmosphere. Typically, at least half the heat energy from the fuel must be wasted since it cannot be cost-effectively converted to electrical energy.

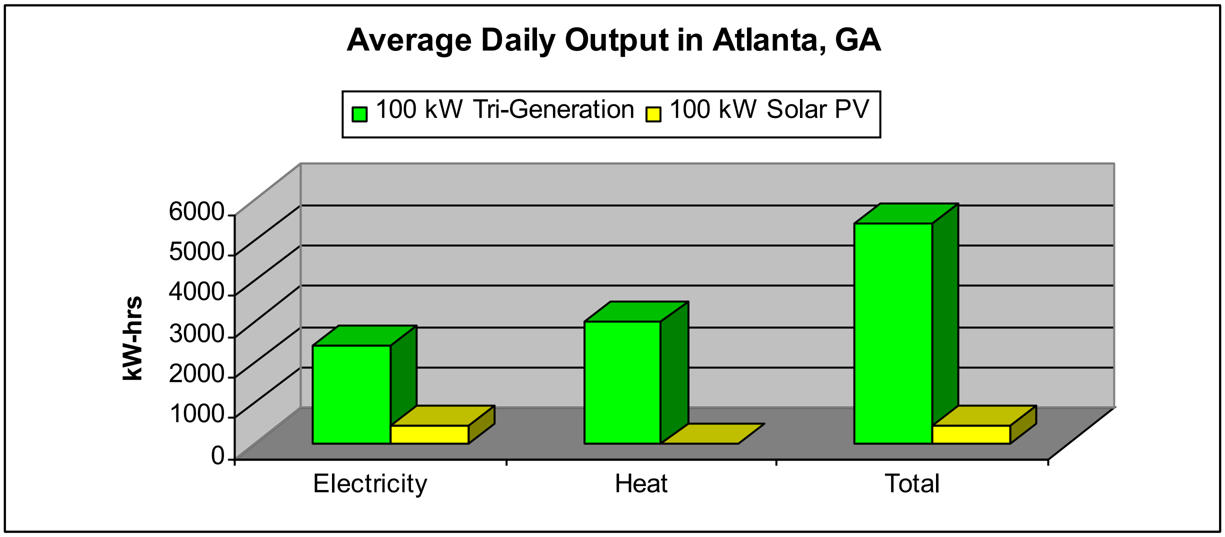
To reduce emissions from electricity, many people turn to on-site photovoltaic panels to produce electricity from sunlight. A solar PV array sized for the peak electrical load of the building can only offset the electricity from the grid for some fraction of the day. Due to clouds, nighttime darkness, and shading, most of the electricity for a building must still come from the grid. Also, any heating or cooling requirements for the building must be produced by ancillary equipment such as natural gas fired boilers or electro-mechanical chillers consuming significant amounts of electricity.

In contrast, an on-site tri-generation system burning natural gas simultaneously produces electricity, heating, and cooling at very high efficiency. An engine burns natural gas to spin a generator to make electricity at 30 to 45% efficiency. The waste heat from engine coolant water and captured exhaust heat is used to generate hot water or steam for free. In the summertime, the hot water can be used to drive a thermal chiller to provide cooling for very little additional energy input. By utilizing a domestic fuel with high hydrogen and low carbon content (CH_4) and also utilizing the low grade excess heat to heat and cool the building, the tri-generation system emits lower rates of CO_2 than solar PV with grid backup. Also, the capital costs for a tri-generation system are far less than a comparably sized solar PV array with separate heating and cooling systems.

According to the U.S. Department of Energy in the year 2009, 2.5 billion tons of CO_2 were emitted by power plants in the U.S.[2] That's more than ten times the combined weight of the American population, or roughly 2,000 pounds per American dumped into the atmosphere. And *that* is the backup power supply for solar PV. For 2009, the DOE states that 3.95 trillion kW-hrs were produced in the U.S.[3] Therefore, we can easily calculate that the American utility grid emitted 1.27 pounds of CO_2 per kW-hr in 2009. This is a notable improvement from the year 2000 when 1.43 pounds of CO_2 per kW-hr were emitted. The decreased CO_2 emissions are due to increased natural gas use, decreased coal use, higher efficiency power plants, and increased use of carbon-free renewable fuels.

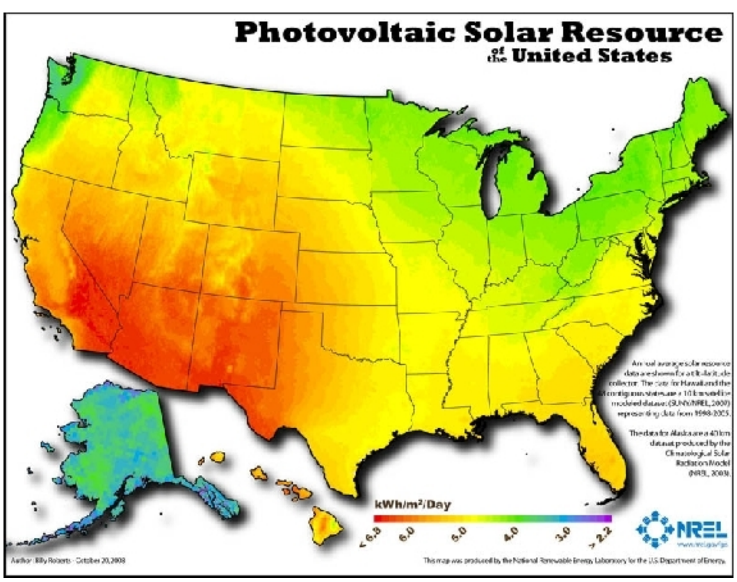
Coal plants in the U.S. emit about 2.12 pounds of CO_2 per kW-hr while large natural gas turbines produce 1.31 pounds of CO_2 per kW-hr.[4,5] Even after hydroelectric, nuclear, wind, and solar generation are included in the national grid calculation, the average American electric utility emits 1.27 pounds of CO_2 into the atmosphere for each kW-hr of electricity produced. This is due to the fact that 44% of the electricity generated in the United States comes from coal, and coal emits 74% of the CO_2 emissions.[3,4] On-site tri-generation systems significantly reduce emissions by burning hydrogen-rich natural gas and then harnessing waste exhaust energy to provide free heating and cooling.

Solar PV, however, can only generate electricity. The other main concerns with solar power are the lack of availability (low capacity factor) and the high cost. Although the sun itself gives off energy continuously, a surprisingly small percentage reaches our rooftops consistently due to clouds and Earth's own shadow. Even in the southern California desert, the sunniest location in the U.S., only about seven full solar hours of sunshine are available during an average day.[6] Similarly, Atlanta, Georgia only receives about 4.5 full hours of solar power per day on average. Therefore, a 100 kW array in Georgia would only produce on average 450 kW-hrs per day. This is in contrast to a 100 kW tri-generation system that would produce 2,400 kW-hrs per day plus 3,000 kW-hrs of free heat. This issue of capacity factor is very important for emissions calculations and return on investment. Atlanta's solar availability is only 4.5 full hours per 24 hour day. That works out to 18.8%. However, a tri-generation system can run continuously except for maintenance and therefore has a capacity factor that approaches 100%.



The sunniest locations in the world have a solar capacity factor of just 25%. Therefore, a solar PV array would effectively produce its full rated capacity for just six hours per day, every day of the year. A nominal 1,000 kW solar PV system in Arizona would produce 2,190,000 kW-hrs per year (1,000 kW x 8,760 hrs x 25%). In a hospital with a constant load, the remaining 6,570,000 kW-hrs would need to be produced by the grid. (Note that this calculation does not include any shading losses or the 23% loss that NREL estimates for a normal solar PV system caused by soiling and DC to AC conversion.[7] This analysis is truly the best case for PV.)

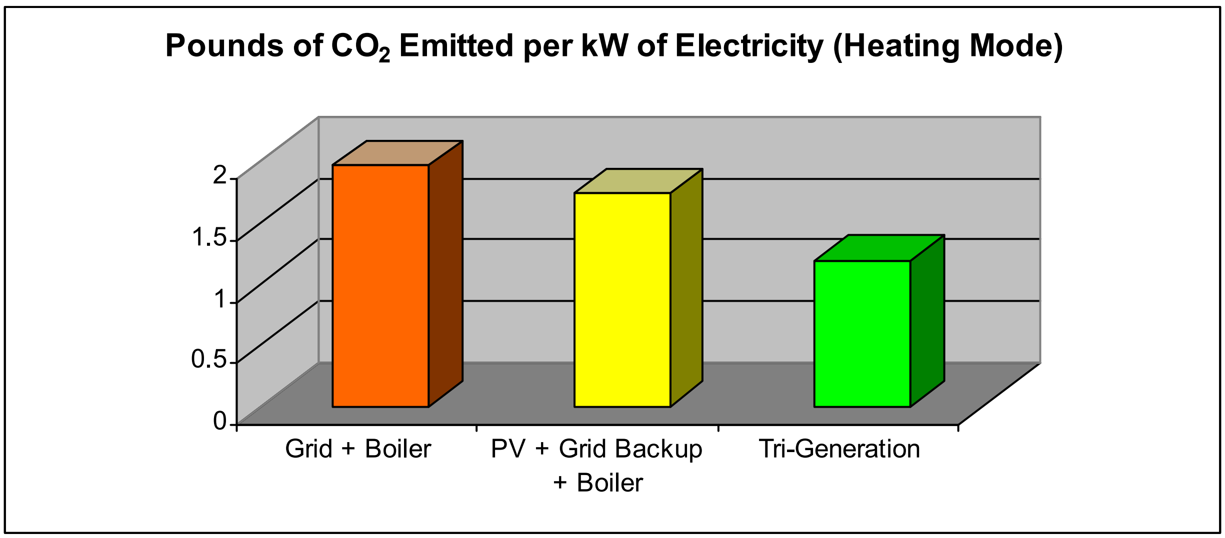
Since the solar PV system must rely on grid power for supplemental electricity most of the time, the net result is a system that emits 0.95 pounds of CO_2 per kW-hr of electricity consumed even with a solar PV array sized for the full capacity of the instantaneous peak load of 1,000 kW. To save more energy, the PV array would need to be larger than the electrical load of the building. The extra energy would then need to be sold back to the grid or stored on site in batteries. Either option would require significantly more financial investment.



Instead of solar PV, another building owner might choose a high efficiency on-site tri-generation system with waste heat capture for heating and cooling. Assuming 33% electrical efficiency for a microturbine, CO_2 emissions of 1.21 pounds per kW-hr would be emitted solely for electricity production. In Arizona, that's not an improvement compared to solar PV, but we have not considered the free waste heat that would be used to offset the heating or cooling loads.

By capturing the waste heat from the microturbine, a traditional boiler can be eliminated. Assuming a standard 82% efficient boiler, an additional 0.49 pounds of CO_2 per thermal kW are eliminated by the tri-generation system. This extra heat can be created for free with zero emissions. That is the benefit of on-site power generation. And it makes the system cleaner than solar PV with grid backup. If the heat is taken as a credit, the tri-generation system emits a net 0.72 pounds of CO_2 per electrical kW-hr. Or taken as a complete system, the tri-generation system in heating mode will emit 1.21 pounds of CO_2 per kW-hr while the equally sized PV array with boiler would emit 1.64 pounds of CO_2 per kW-hr. This is a 26% savings for the tri-gen system compared to the best case for solar PV. In other locations outside the desert, the analyses make PV look far worse due to lower solar capacity factors.

For example, in New Jersey, the solar PV capacity factor is only 18 percent. A typical building with a PV electric array producing 1,000 kW of electricity with grid backup plus 1,421 kW of thermal output from an 82% efficient boiler will emit 1.73 pounds of CO_2 per kW-hr of electricity produced over the course of an average day. But an on-site microturbine tri-generation system would only emit 1.21 pounds of CO_2 per kW-hr in combined power and heating mode. That is a 30% reduction.

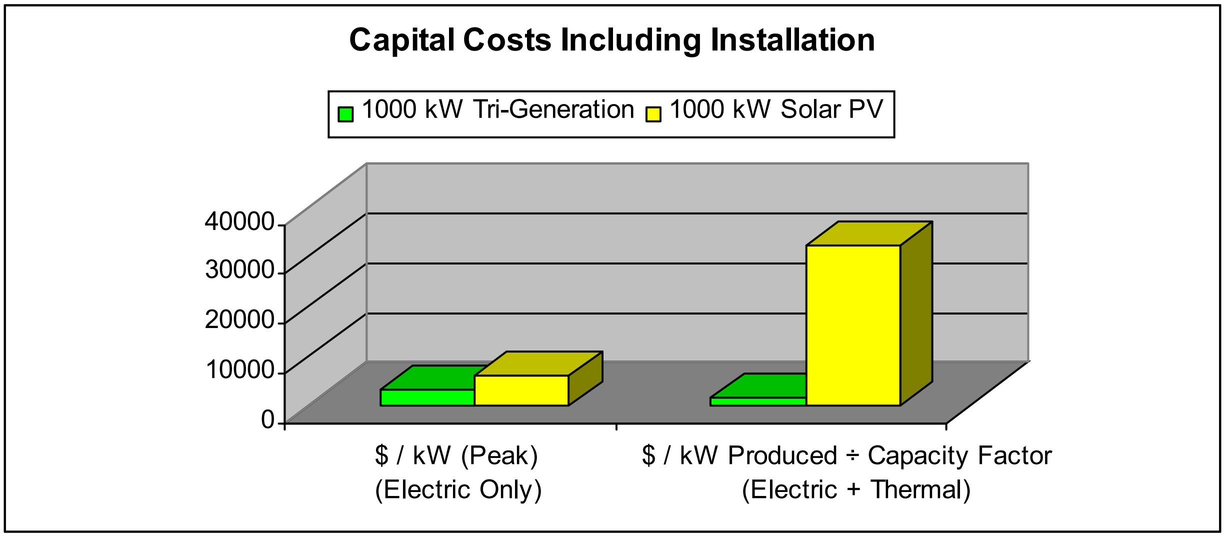


Even if the heat is not used, the solar PV system will emit 1.05 pounds per kW-hr while a reciprocating engine generator will emit 0.95 pounds per kW-hr. In New Jersey, the natural gas generator will emit less CO_2 than PV with grid backup even if the heat is not captured at all.

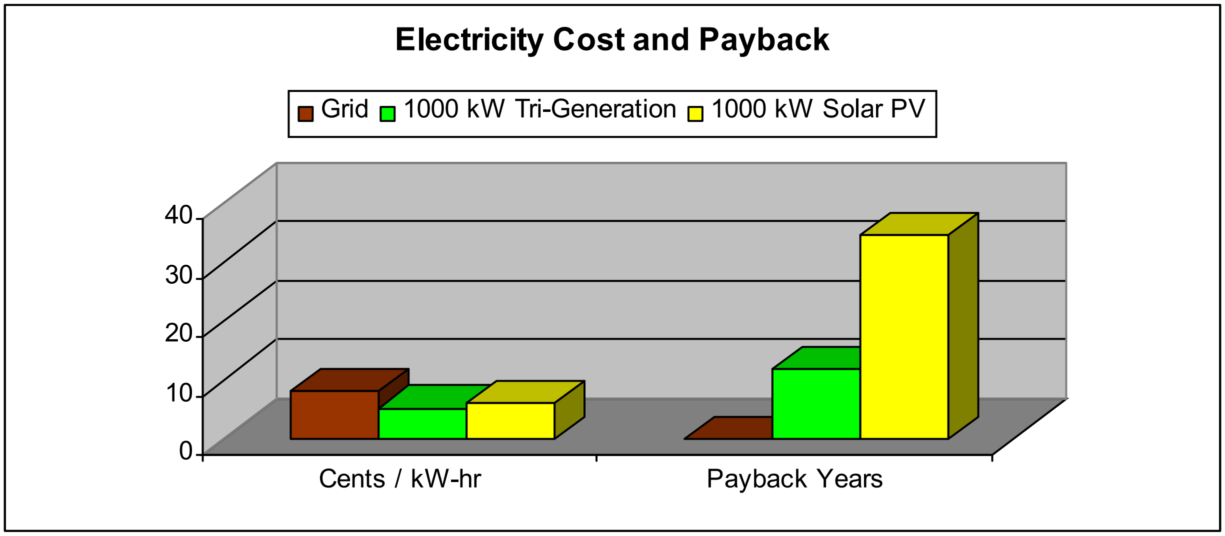
This has political consequences as well. Tax dollars are paying for solar PV panels all over New Jersey that only produce electricity 18 percent of the time.[8] Tri-generation systems could do the job 24/7 with fewer emissions at much less than half the capital cost.

What about summertime in a data center?
A tri-generation system sized at 1,000 kW of electricity output can provide enough heat to drive a 250 ton (3,000,000 Btu/hr) cooling system for free by using an adsorption or absorption chiller. The same electrical and cooling capacities using PV would require a 1,000 kW array plus a 250 ton chiller driven by grid power. Assuming an electrical efficiency for the chiller of 0.65 kW per ton, an additional 163 kW of grid power would be required even while the PV array was active. At night, the building would require the full 1,163 kW of power entirely from the grid to match the output of the 1,000 kW tri-generation system. Therefore, in Arizona with a 25% solar capacity factor, the overall net emissions rate for the solar PV system plus chiller would be 1.16 pounds of CO_2 per kW-hr of electricity produced. In New Jersey, with the lower capacity factor, the PV system would emit 1.26 pounds of CO_2 per kW-hr.

With tri-generation, however, the full electrical output of the generator could be used for needs on site while the chilled water would be a free byproduct. Therefore, using a 1,000 kW reciprocating engine/generator delivering 250 tons of cooling output, we would find emissions of 1.06 pounds of CO_2 per kW of electricity produced in either Arizona or New Jersey. That would result in emissions savings compared to solar PV of 8.6% and 15.9%, respectively.



A high efficiency tri-generation system would not only cut the emissions significantly. It would also reduce the capital cost. PV arrays require about $5 to $6 per watt installed, just for the solar system. In contrast, a complete tri-generation system including the heat recovery system, chiller, pump package, and installation would cost about half that. Although the tri-generation system would continue to consume fuel while the solar PV system would not, the low cost electricity produced by the tri-gen system would dilute the savings from a PV system. According to my calculations, the owner that chooses a solar PV system would need at least 30 years to recover their investment (at 0% interest) and would emit more CO_2 over that time compared to tri-gen. In fact, according to NREL's own calculator, a solar PV system in Atlanta, Georgia would take 60 years to pay back without government incentives.[9] That is far longer than the projected life of the solar cells.



What if I don't need heating or cooling?
As stated above, in locations such as New Jersey, a high efficiency generator burning natural gas only being used to produce electricity with no heat capture will still emit less CO_2 than a PV array with grid backup. To gain even higher efficiency, an Organic Rankine Cycle heat recovery package could be used to boost the electrical output and reduce emissions by 10% or more. Again, the cost is significantly lower than a PV system. And the net result is a system with lower CO_2 emissions than PV with grid backup.

If America's goals are to reduce CO_2 emissions, use a domestic fuel, and spend the least amount of money possible, a serious consideration of natural gas tri-generation systems should be made. Site conditions should be evaluated for the benefits of using tri-generation's free waste energy for heating, cooling, and additional electricity production.

Let me close with a note stating that I am certainly in favor of harnessing solar power and other renewable energy sources. But with a limited amount of money to spend, the most cost-effective solution for CO_2 reduction should be implemented. In many cases, tri-generation will unquestionably be the better solution. Perhaps future advances in solar technology will result in mass produced, inexpensive solar cells, solar mounts, inverters, and energy storage. But we cannot change the weather. Solar PV will always be handcuffed by limited run-hours and limited solar intensity. For most parts of the U.S., a tri-generation system will emit significantly less CO_2 than a solar PV project due to the limited operating hours of solar PV and the continued emissions from the grid.

Sources:

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