Supercritical CO_2 Turbine Integration: Comparing PV + Heat Pump vs. Concentrated Solar for Thermal Power Generation

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https://infinityturbine.com/comparing-solar-pv-and-csp-by-infinity-turbine.html

A comparison of solar photovoltaic with heat pump systems versus concentrated solar thermal in supplying heat to a supercritical CO_2 turbine generator. The article evaluates which approach delivers higher-quality heat and greater electrical generation potential per square meter of sunlight.

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Solar PV and Heat Pump vs. Concentrated Solar Thermal CSP

Overview

Supercritical carbon dioxide (sCO_2) turbine generators are a new class of compact, high-efficiency systems that convert heat into electricity using CO_2 as the working fluid. These turbines require a high-temperature heat source, typically ranging from 300 to 700 degrees Celsius. The challenge is identifying which solar-based system—solar PV combined with a heat pump or concentrated solar thermal—can deliver the most suitable and efficient heat for the sCO_2 cycle.

This article compares both methods for one square meter of sunlight at midday under clear-sky conditions and assesses which produces higher-quality thermal energy and greater total power output.

1. The Two Solar Approaches

A. Solar PV + Heat Pump

In this configuration, a solar photovoltaic panel converts sunlight directly into electricity. The generated electricity powers a heat pump that transfers heat from ambient air or a secondary loop into a storage or process fluid.

Modern PV panels operate with efficiencies of about 20 to 22 percent. Heat pumps, depending on temperature lift, can have coefficients of performance (COP) between 3 and 6 for moderate temperature differentials. The result is a large quantity of low• to medium-temperature heat (generally below 100 degrees Celsius).

While this system is excellent for building heating and low-temperature applications, it does not generate the high-grade heat required for a supercritical CO_2 turbine. Even though the overall energy capture is high, the heat quality is too low to reach turbine inlet conditions.

B. Concentrated Solar Thermal (CSP)

Concentrated solar systems use mirrors or lenses to focus sunlight onto a receiver, achieving temperatures from 300 up to 700 degrees Celsius or higher. The thermal energy can then be used directly to heat a working fluid such as molten salt, pressurized CO_2, or air, which drives a turbine or generator.

For sCO_2 turbines, CSP is almost ideal. The concentrated heat provides the required temperature and energy density to bring CO_2 into the supercritical region—typically above 31 degrees Celsius and 74 bar, but operating much higher in practical turbine systems.

Even though CSP efficiency per square meter may be lower due to optical and thermal losses, the resulting heat is high-quality thermal energy suitable for direct mechanical or electrical generation.

2. Quality of Heat Comparison

• PV + Heat Pump System:

Produces heat that is relatively low in temperature (below 100 degrees Celsius). This level of heat is valuable for space heating or water heating but cannot efficiently drive a thermodynamic cycle like sCO_2. Any attempt to upgrade this heat to turbine inlet temperatures would require additional compression or resistive heating, reducing efficiency.

• Concentrated Solar Thermal System:

Produces high-temperature heat suitable for direct coupling to a sCO_2 turbine or intermediate thermal storage. The heat quality matches the turbine's thermodynamic requirements, enabling efficient power conversion.

Therefore, when evaluating heat quality for sCO_2 turbine integration, CSP provides the superior temperature range and energy density.

3. Electrical Output Potential

• PV + Heat Pump Pathway:

A PV panel can generate approximately 0.20 to 0.22 kilowatt-hours of electricity per square meter per hour under full sun. This power can directly feed the grid or support auxiliary loads. However, when this energy is diverted to a heat pump, it produces thermal energy, not mechanical shaft power. To drive an sCO_2 turbine, the low-grade heat must first be raised to high temperatures, requiring further conversion steps and electrical input. As a result, the total round-trip efficiency from sunlight to sCO_2 turbine output is low.

• CSP Pathway:

Concentrated solar delivers roughly one kilowatt-hour of solar input per square meter per hour, but after losses, about 0.5 to 0.7 kilowatt-hours of usable high-temperature heat remain. When this heat is converted through an sCO_2 turbine (with typical thermal-to-electric efficiency between 25 and 45 percent, depending on inlet temperature and cycle design), the result is approximately 0.15 to 0.3 kilowatt-hours of electricity per square meter per hour.

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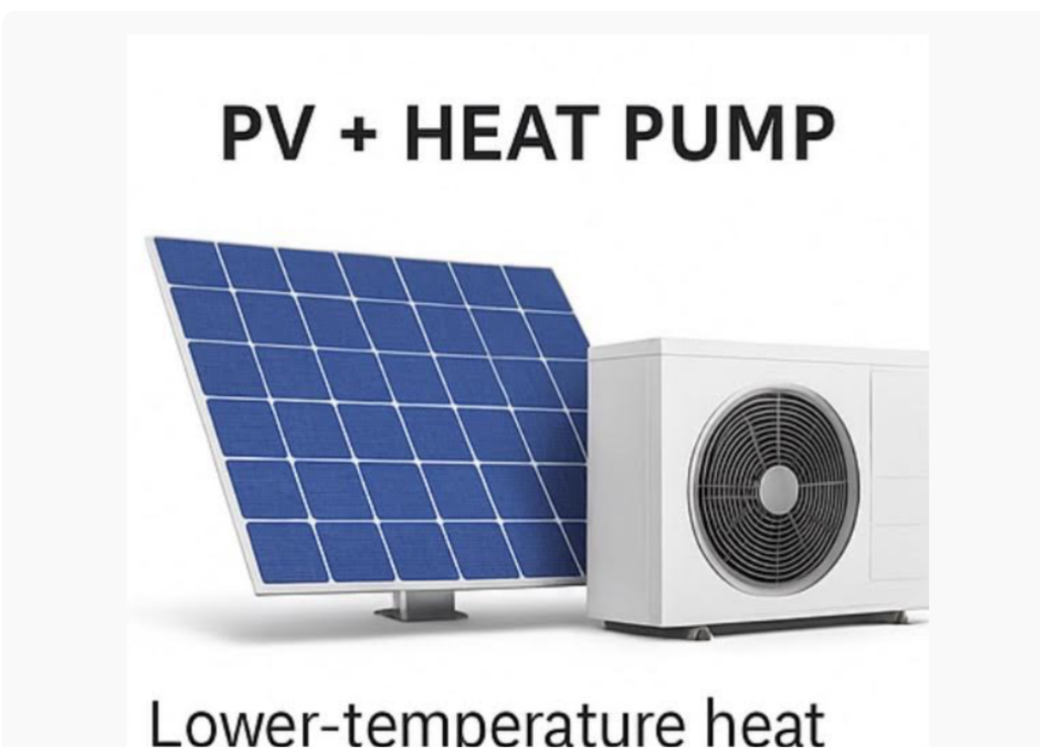
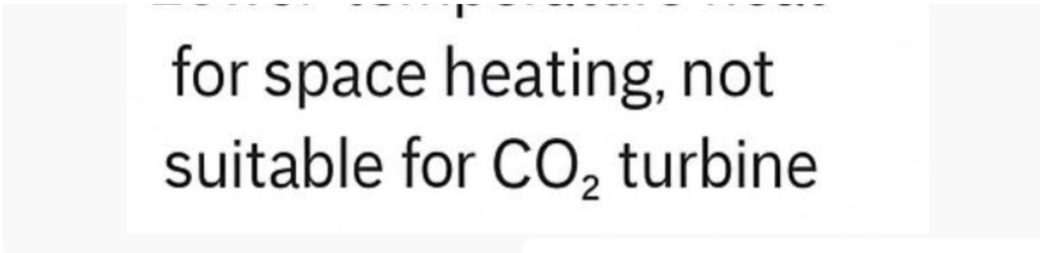

PV + HEAT PUMP
Lower-temperature heat



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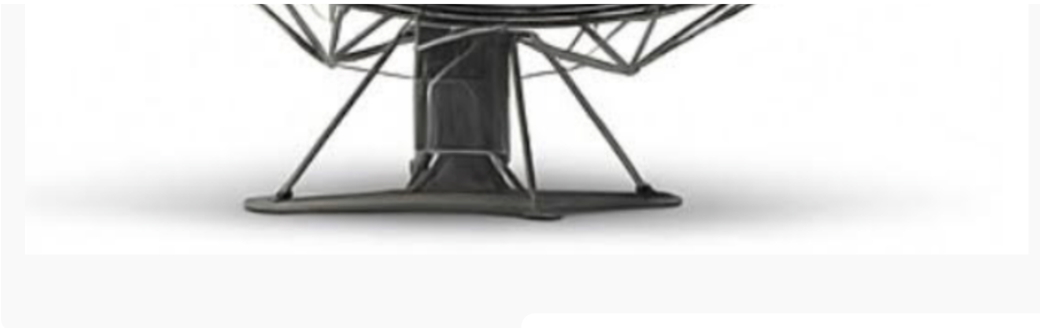

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