Direct-Fired Supercritical CO_2 Combined Cycle: A Closed-Loop Alternative to Gas Turbines
Meta Description

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A technical assessment of a direct-fired, closed-loop supercritical CO_2 combined cycle that replaces air-breathing gas turbines with a dual sCO_2 Brayton architecture to achieve 46–56 percent net LHV efficiency.

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By eliminating the air-breathing gas turbine and directly coupling natural gas combustion to supercritical CO_2 Brayton cycles, a new class of closed-loop combined cycle power systems can deliver higher efficiency, simpler heat recovery, and greater scalability than legacy microturbine-based architectures.

Replacing the Gas Turbine with a Direct-Fired sCO_2 Combined Cycle

Conventional natural-gas power systems rely on air-breathing gas turbines as the primary Brayton cycle, followed by steam or organic Rankine bottoming cycles to recover exhaust heat. While mature, this architecture carries inherent efficiency penalties associated with air compression, large exhaust mass flows, and limited temperature matching between the turbine exhaust and bottoming cycles.
An alternative approach is to eliminate the air-breathing turbine entirely and instead convert natural gas heat directly into power using a closed-loop supercritical CO_2 (sCO_2) combined cycle. In this configuration, natural gas is burned in a high-efficiency burner, and the heat is transferred through compact, high-temperature heat exchangers directly into one or more closed sCO_2 Brayton cycles.
The result is a system that preserves the thermodynamic advantages of Brayton operation while avoiding the inefficiencies of open-air compression and exhaust dilution.

System Architecture Overview
The proposed system consists of two closed CO_2 power loops arranged in a temperature cascade:
1. Topping sCO_2 Brayton Cycle
 Natural gas is combusted in a controlled burner. Hot flue gas passes through a high-temperature CO_2 heater, raising the primary sCO_2 loop to turbine inlet temperatures in the 650–715 °C range. This loop uses an advanced Brayton configuration such as partial-cooling or recompression, with high-effectiveness recuperation to minimize compression work and maximize cycle efficiency.
2. Bottoming sCO_2 Brayton Cycle
 Flue gas exiting the topping heater still contains substantial sensible heat. A second, independent sCO_2 loop captures this mid-temperature energy (typically in the 250–450 °C range) and converts it into additional electrical power. This bottoming loop is optimized for heat recovery rather than peak cycle efficiency.
Both loops are fully closed, using CO_2 as the sole working fluid, and reject heat through air coolers operating at ambient conditions (70 °F in the design case).

Why Direct-Fired sCO_2 Outperforms Legacy Microturbines
This architecture fundamentally changes where efficiency is gained and lost:
• Elimination of Air Compression Losses
 Traditional gas turbines devote a large fraction of shaft work to compressing atmospheric air. Near-critical CO_2 compression requires far less work, particularly when well-managed around the critical region.
• Higher Effective Turbine Inlet Temperatures
 Microturbine exhaust temperatures typically limit bottoming cycle performance. Direct firing allows the primary sCO_2 turbine to operate at temperatures comparable to large utility-scale gas turbines, but in a compact, closed-loop system.
• Superior Heat Utilization
 The dual sCO_2 configuration addresses a known limitation of single-loop sCO_2 cycles: the narrow temperature window of heat addition. By splitting heat recovery across two Brayton loops, the system extracts work from a much larger portion of the flue-gas temperature glide.
• Working Fluid Simplicity
 CO_2 is non-flammable, inexpensive, globally available, and free from regulatory phase-down risk, unlike many organic working fluids.

Expected Efficiency Performance
With modern combustor and heat-exchanger design, realistic performance expectations for a direct-fired dual sCO_2 system are:
• Topping sCO_2 loop net efficiency: approximately 43–49 percent (LHV), after accounting for heater losses, pressure drops, and auxiliaries.
• Bottoming sCO_2 loop contribution: an additional 3–7 percentage points (LHV), depending on how aggressively residual flue-gas heat is recovered.