Low-Cost Strategies for Pressurizing CO_2: Best Practices & Cost Benchmarks

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https://infinityturbine.com/infinity-turbine-co2-compression-strategies-and-pumping-liquid-is-more-efficient-than-gas-compression.html

Explore cost-effective methods for pressurizing carbon dioxide. Compare gas compression vs liquefaction + dense-phase pumping. Key benchmarks, efficiencies, and dollar-per-ton metrics at $0.10/kWh electricity.

This webpage QR code

PDF Version of the webpage (maximum 10 pages)

Best low-cost way to pressurize CO_2

Pump it as a liquid whenever you can (and only compress as a gas when you must). The physics is simple: once CO_2 is condensed, the specific work to raise pressure is ~ΔP/ρ, which is tiny compared with gas compression work. In practice, the cheapest configurations are:

1. Hybrid compress → condense → pump (most practical overall)

Use a multi-stage intercooled gas compressor only up to the point where CO_2 can be condensed (near/just below the critical region), then finish the pressure rise with a liquid CO_2 pump to your pipeline/storage pressure (e.g., 110–150 bar). This "pump last" step cuts the energy penalty vs. all-gas compression. ([Global CCS Institute][1])

2. All-liquid pumping (cheapest per bar, but only if you already have liquid)

If your process already provides liquid CO_2 (e.g., a cold, condensed product stream), a cryogenic liquid CO_2 pump can take it to 100–350 bar with very low power compared with gas compression. (These are commodity machines in cylinder-filling and industrial-gas service.) ([CNC D Cryogenic Tank][2])

Why this wins: for a pump raising liquid CO_2 from 70 → 110 bar, the specific work is roughly
$w approx Delta P/rho sim 4times10^6 text{Pa}/900 text{kg·m}^{-3} approx 4.4times10^3 text{J·kg}^{-1}$
≈ 0.0012 kWh/kg = 1.2 kWh/ton—orders of magnitude below gas compression. (That relation is the standard flow work Pv result.) ([Pressbooks][3])

What gas-only compression costs you (for context)

Authoritative CCS references put gas compression to ~110 bar at roughly 0.4 GJ/ton ≈ 111 kWh/ton (before transport/storage). At $0.10/kWh, that's about $11 per ton of CO_2 just for compression. ([IPCC][4])

With good design (multi-stage, aftercooling, optimized staging), that number can be trimmed, but it's still in the ~90–140 kWh/ton band for many cases—again, $9–$14 per ton at $0.10/kWh. ([Global CCS Institute][5])

What liquid pumping costs you

As shown above, pumping the last 40 bar (70 → 110 bar) as a liquid is roughly 1–2 kWh/ton, i.e., $0.10–$0.20 per ton at $0.10/kWh—two orders of magnitude cheaper per bar than gas compression. Commercial LCO_2 pumps are widely used for exactly this reason. ([CNC D Cryogenic Tank][2])

> Caveat: you must condense CO_2 first. Condensation removes latent heat (order ~180 kJ/kg near ambient), which is thermal load, not pure electric compression work. If you're already rejecting that heat (e.g., as part of your capture/liquefaction train), the marginal electric cost of the pump step remains extremely low. ([Engineering ToolBox][6])

Recommended low-cost architecture (ranked)

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Pressurizing CO_2 efficiently is critical for applications like pipeline transport, enhanced oil recovery, industrial usage, and geological sequestration. Given electricity at $0.10 per kilowatt-hour, here's what the research shows about how to minimize cost while maintaining reliability and safety.

1. Key metrics & thermodynamic background

Dense phase / liquid CO_2: When CO_2 is compressed above its critical pressure (≈ 7.38 MPa or ~1070 psi) and held at suitable temperature, it behaves like a dense fluid—with much higher density than gas, but still compressible. Using dense phase or liquid conditions greatly reduces the work required for further pressure increases. ([The Department of Energy's Energy.gov][1])
Pump vs compressor work: Compressing gas requires many stages, inter-cooling, high mechanical complexity and energy. By contrast, once liquefied or in dense phase, pumping further pressure has a much lower specific energy cost ($\Delta P/\rho$). Research shows replacing late gas compression stages with dense phase pumping can yield large energy savings. ([Cryogenic Society of America][2])

2. Comparison of compression pathways

Pathway	Description	Energy & cost trade-offs
All-gas compression	Gas from low pressure → high pressure using multi-stage compressors with inter-coolers etc.	Higher energy usage. Literature indicates that compressing CO_2 gas to ~110-150 bar using gas only can consume many tens to over one hundred kWh per ton of CO_2. Cost per ton at $0.10/kWh → several dollars per ton just for compression. ([POWER Magazine][3])
Hybrid compression → dense-phase pumping	Compress gas to just below/around critical point, condense or liquefy, then pump dense fluid to final pressure.	Offers significant energy savings. A case study showed replacing last compressor stages with a centrifugal liquid pump in the dense phase yields over 50% savings in compression work for those stages. Overall, this hybrid method can reduce the compression energy by several percent of the total CO_2 processing cost. ([Cryogenic Society of America][2])
Liquid CO_2 pumping	If CO_2 is already in liquid or dense state, use high-pressure pumps to raise pressure further rather than gas compressors.	Lowest incremental energy cost for additional pressure. Pumps are simpler, efficient, and cost per ton for these stages often drops to fractions of a $/ton of CO_2, when electricity cost is $0.10/kWh. References from dense phase injection and pipeline work show feasibility in this domain. ([Abset][4])

3. Typical energy and cost figures

Replacing final gas compression stages with dense fluid pumping (for example, going from ~40-80 bar upward) can reduce energy input for those stages by more than 50% in many designs. ([Cryogenic Society of America][2])
For large-scale CO_2 pipeline / transport systems, pumps designed for dense CO_2 can operate at pressures up to ~100 bar (≈1500 psi) with high throughput, holding CO_2 in dense or supercritical state. ([Abset][4])
The cost of compressing CO_2 gas to pipeline pressures (e.g. ~110-150 bar) is often in the tens to hundreds of kWh per ton of CO_2. If you assume compressing with all-gas, the electric energy cost could be $8-$15 per ton at $0.10/kWh, depending on pressure ratios, aftercooling, etc. Hybrid approaches reduce that substantially. (Exact numbers vary with inlet/outlet pressure, temperature, compressor efficiency.) ([POWER Magazine][3])

4. Best practices for minimizing cost

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4. Best practices for minimizing cost

1. Operate above the CO_2 critical pressure where possible, so you can use dense phase fluid mechanics and pumping rather than high work gas compression. Aim for inlet feed to be as warm as safely possible but above critical pressure.
2. Use multi-stage compression with intercooling up to the condensation threshold. Then if feasible, condense or liquefy CO_2 before final pressure raise.
3. Choose high efficiency pumps specifically rated for dense CO_2 service: materials, seal design, inlet/outlet conditions must handle high pressure, temperature, and any CO_2 impurities. ([Abset][4])
4. Recover heat: Use waste heat or cooling systems to condense or cool CO_2 before pumping; cooling reduces compression energy and improves overall thermodynamic efficiency.