ENGINEERING COMPARISON · INFINITY TURBINE LLC · YUKON PLACER GOLD APPLICATION · NOVEMBER 2026

CO_2 as the Working Fluid: Purpose-Built CO_2 Piston Expander vs a Traditional Steam Engine Run on CO_2

Same 500,000 BTU/h log boiler with 800 °C flue gas, same 5 °C creek/glycol cooling, the same transcritical CO_2 loop with recuperator, and hydraulic output at 207 bar (3,000 psi). The only change is the piston machine: a new design built for CO_2, or an old-style steam engine converted to run on it.

32.2 kW
Purpose-built CO_2 piston, 500 °C / 200 bar · 43 hp net

13–16 kW
Old steam engine rebuilt for CO_2, 300–350 °C · 18–21 hp net

5.2 kW
Unmodified engine in a pressurised crankcase · 7 hp net

12–15×
CO_2 mean effective pressure vs steam (58 bar vs 3–5 bar)

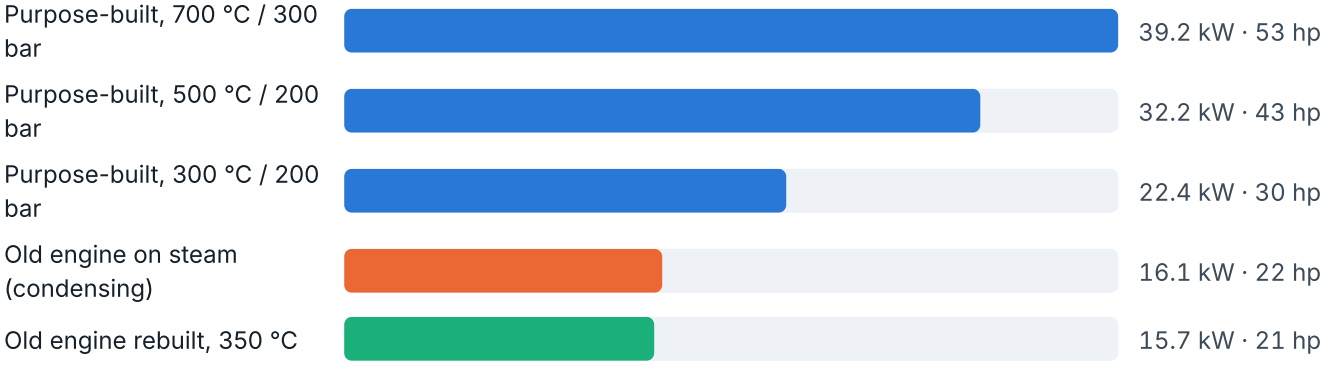
01 Answer in brief

A traditional steam engine cannot simply be filled with CO_2. Its cylinders, valve chest and rod packing are cast iron, built for 8–17 bar (125–250 psi). A CO_2 cycle that condenses on 5 °C water already sits at **46 bar (666 psia) on the low side** and 200 bar (2,900 psia) on the high side. Even the exhaust pressure is three times the old engine's rating.

CO_2 also produces about **12–15 times more work per litre of swept volume** than steam. Its mean effective pressure is about 58 bar, against 3–5 bar in a steam engine. That is good for size, but it means piston and rod loads 12–17 times what the old crank, crosshead and bearings were built for.

There are three ways to make an old engine run on CO_2. The best gives about **13–16 kW (18–21 hp) net**, which is less than the same engine produces on steam (16 kW condensing) and **half of what a purpose-built CO_2 piston expander delivers (32.2 kW, 43 hp)**. The old engine is not the way to go. But several of its design features are well worth carrying into the purpose-built CO_2 machine (Section 06).

Net hydraulic power from 500,000 BTU/h of logs

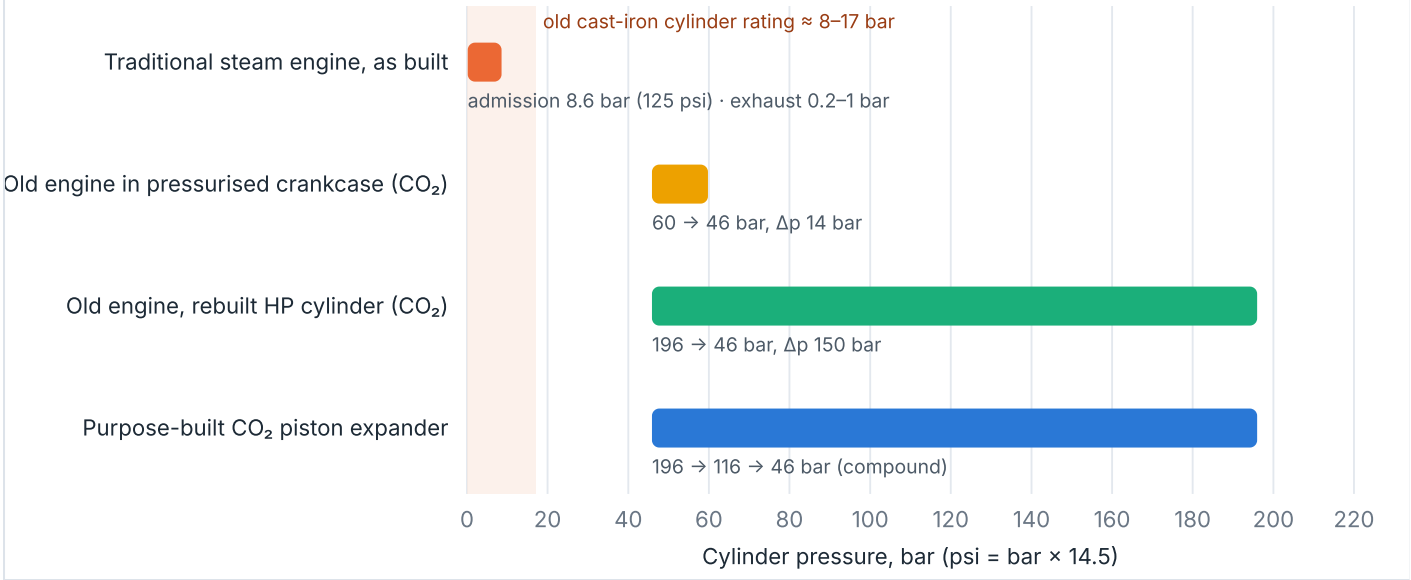


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Net = oil power at 207 bar after driving the CO_2 feed pump. Colours: ■ purpose-built CO_2 piston, ■ old engine rebuilt for CO_2, ■ old engine in pressurised crankcase, ■ the same old engine on steam (from the previous study). The low-pressure CO_2 gas cycle produces no net power and is not shown.

02 The core problem: pressure and force



Operating pressures. A CO_2 cycle that condenses on 5 °C water stays above 46 bar everywhere, well outside the 8–17 bar rating of traditional cast-iron steam cylinders.

Example: a typical old 40 hp horizontal mill engine

Item	On steam (as built)	Same bore on CO_2
Bore × stroke		9 × 12 in · 229 × 305 mm, double-acting, ~200 rpm
Working pressure	8.6 bar · 125 psi	196 bar · 2,840 psi
Peak pressure difference	≈ 8.6 bar	150 bar (196 → 46)
Peak rod load	35 kN · 7,950 lbf	**617 kN · 138,700 lbf (17×)**
Mean effective pressure	3–5 bar	45–58 bar
Indicated power	≈ 29 kW · 39 hp	would be ~10× (but the engine breaks)

Representative dimensions for an engine of this class; individual engines vary.

What fails first

- **Cast-iron cylinders and valve chest:** a pressure (burst) hazard at 46–200 bar. Brittle failure throws fragments.
- **Slide (D) valve:** pressure holds it against its seat. At 150 bar across a ~100 cm² valve face, the seating force is about 150 kN (≈ 34,000 lbf), 17 times the steam load, so the valve cannot be moved. It must be replaced with balanced piston valves or poppets.
- **Rod gland packing:** fibre or metallic packing built for 15 bar steam will not seal 46–200 bar CO_2. High-pressure chevron PTFE stacks, as in CO_2 plunger pumps, are needed.
- **Crank, crosshead, bearings:** rated for about 35 kN peak, against 617 kN on CO_2 at the original bore.
- **Cylinder oil:** CO_2 dissolves into oil and thins it, washes it off the walls, and carries it into the recuperator and the 500 °C+ heater coil, where it cokes.
- **Clearance volume** of 6–12 % (normal for steam) wastes dense CO_2 unless the engine is built to recompress it.

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03 Three ways to run an old steam engine on CO_2

Route	What is done	CO_2 in	Expander kW	CO_2 pump kW	Net hyd. kW / hp	Verdict
A. Keep the engine's 15 bar rating; closed CO_2 gas loop, 5 → 15 bar, with a piston compressor on the same crank	CO_2 cannot condense at 15 bar with 5 °C water (it would need −28 °C), so it must stay a gas and be compressed	300 °C, 15 bar	92	129 (compressor)	**negative**	**Does not run** — compressing the gas takes more work than the engine produces
B. Pressurised crankcase: put the unmodified engine inside a 70 bar pressure vessel at exhaust pressure	Cylinder parts see only Δp ≈ 14 bar; CO_2 boils subcritically at 60 bar	300 °C, 60 bar	8.6	1.4	5.2 / 7.0	**Not worth it** — 1.3 : 1 pressure ratio, and a multi-tonne coded pressure vessel around the engine
C. Rebuild: new forged-steel HP cylinder sleeved to Ø55 mm (2.2 in), poppet valves, high-pressure gland; old frame, crank and flywheel kept	Bore shrunk until the rod load is back to the original 35 kN rating; oil-lubricated, so the CO_2 is limited to 300–350 °C	300–350 °C, 200 bar	31–34	9.9	13.2–15.7 / 17.6–21.0	**Works, poorly** — it is really a new expander on an old frame

Why route C delivers only about the engine's original steam horsepower. Power = rod force × piston speed. If the rod load must stay at the old 35 kN rating and the speed stays near 200–300 rpm, the power stays near the engine's original steam rating (≈ 29–34 kW indicated). Getting the 45 kW of expander power the boiler can support would need a larger, 60 hp-class engine, weighing several tonnes. A purpose-built CO_2 expander of 250–450 kg does the same job.

Route C also gives up efficiency: oil-lubricated rings and an old frame limit the CO_2 to about 300–350 °C instead of 500 °C. The rebuilt valve gear and leaky, wide-clearance cylinders reach an assumed 65 % expander efficiency (80 % for the purpose-built machine). And driving a rotary hydraulic pump from the crank costs 88 % mechanical × 90 % pump efficiency, against 92 % for a direct plunger.

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04 The purpose-built CO_2 piston expander

- **Small, forged cylinders** rated 250–300 bar: HP Ø63 mm / LP Ø86 mm × 100 mm stroke at about 400 rpm (crank version), or HP Ø82 / LP Ø111 × 400 mm at 30 cycles/min (free-piston tandem driving hydraulic plungers). Peak gas loads are 28–32 kN, which a small, light running gear can carry.
- **Compound expansion** 196 → 95 → 46 bar, giving 2.1 : 1 per stage and keeping force variation modest.
- **Hydraulically actuated poppet valves**, timed by the PLC, so cutoff can be varied while running.
- **Oil-free hot end:** carbon-graphite or PTFE-bronze rings, so no oil reaches the recuperator or heater. This allows CO_2 at 500 °C (932 °F), and the hotter CO_2 alone is worth +10 kW over 300 °C.
- **Cooled distance piece** between the hot cylinders and the hydraulic or crank end.
- **Low clearance (≈ 2–3 %)** with exhaust-closure recompression ("cushioning").

At 500 °C / 200 bar	Metric	Imperial
CO_2 flow	0.301 kg/s	2,390 lb/h
Expander work	45.1 kW	60.5 hp
Gross hydraulic	41.5 kW	55.7 hp
CO_2 pump	7.9 kW	10.6 hp
Net hydraulic	**32.2 kW**	**43.2 hp**
Oil at 207 bar	120 L/min	31.8 gpm
Mean effective pressure	58 bar	845 psi
Swept volume flow (LP)	7.75 L/s	16.4 cfm
Estimated expander mass	250–450 kg	550–1,000 lb

At 300 °C (the same temperature limit as the converted engine) the purpose-built machine still delivers 22.4 kW. At an expander efficiency of 70 % instead of 80 % it delivers 28.3 kW at 500 °C.

05 Side-by-side comparison

Criterion	Purpose-built CO_2 piston expander	Old steam engine rebuilt for CO_2 (route C)
Net hydraulic power	**32.2 kW · 43 hp**	**13–16 kW · 18–21 hp**
Wood → net hydraulic	22.0 %	9.0–10.7 %
Max CO_2 temperature	500 °C (to 700 °C with Ni-alloy)	300–350 °C (oil limit)
Pressures	200–300 bar, designed for it	200 bar in new HP parts; the old frame is the weak link
Cylinders / valves	Forged steel, poppet valves, variable cutoff	New HP cylinder + poppets; the original valve gear is mostly discarded
Lubrication	Oil-free hot end	Cylinder oil → oil separator needed; coking risk in the heater
Rod seal	Cooled distance piece, high-pressure PTFE stack	Retrofit high-pressure gland in an old stuffing box
Drive to hydraulics	Direct plungers (92 %) or crank + pump	Crank → belt/coupling → rotary pump (≈ 79 %)
Size / mass	≈ 1 × 0.6 m, 250–450 kg	Engine + flywheel ≈ 2–3 t (4,400–6,600 lb)
Transport to a Yukon claim	Pickup or skid	Heavy-haul, crane

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Cost driver	New design and certification	Antique engine purchase + almost all hot parts new anyway
Pressure-safety case	**Clean, coded from the start**	**Mixed old cast iron + new high-pressure parts; hard to certify**
Field repair	Moderate (rings, valve seats are consumables)	Good on the running gear; HP parts as specialised as the new machine

06 What the old steam engine does teach the CO_2 design

Ideas to carry over

- **Variable cutoff for load control**, as with link motion, Corliss trip gear or a governor. Here it is done with PLC-timed poppets, so output follows the wash-plant load without throttling.
- **Compounding** (HP → receiver → LP) to keep the pressure ratio and force variation per cylinder moderate.
- **Uniflow exhaust** (exhaust ports uncovered by the piston at the end of the stroke) for low exhaust losses, plus deliberate cushioning recompression.
- **Poppet valves** (Lentz/Stumpf practice) instead of slide valves. They are the only valves that survive high pressure difference.
- **Crosshead plus distance piece** to keep the hot cylinder away from the cold running gear and hydraulics.
- **Low speed, flywheel and belt drive** to a standard hydraulic pump. That gives a robust, field-serviceable drive at 200–400 rpm.

Where an old engine still has a role

- **On steam, as intended:** 16 kW (21 hp) condensing, or about 10 kW plus 150 kg/h of thaw steam non-condensing. That beats the same engine converted to CO_2.
- **As a test-bed frame** for the first CO_2 cylinder and valve trials at low power. The crank, flywheel and crosshead are proven, and the CO_2 cylinder can be sized to the frame's 35 kN rating.
- **For marketing and heritage** in the Yukon: a visible link to Klondike-era steam, with a modern CO_2 power unit doing the real work.

07 Conclusions

Build a purpose-built CO_2 piston expander; do not convert an old steam engine

- An unmodified old steam engine cannot run a CO_2 cycle with 5 °C cooling. Its 8–17 bar rating is below even the 46 bar CO_2 exhaust pressure. Running it on a low-pressure CO_2 gas loop produces **no net power**.
- Enclosing the old engine in a pressurised crankcase works only at a 1.3 : 1 pressure ratio: **5.2 kW net**, and a large pressure vessel.
- Rebuilding the engine with new high-pressure cylinders on the old frame gives **13–16 kW net**, limited by rod load, oil temperature and conversion losses. That is less than the same engine produces on steam.
- A **purpose-built CO_2 piston expander gives 32.2 kW (43 hp) net at 500 °C / 200 bar**, or 39.2 kW at 700 °C. That is 2–2.5× the best conversion, at roughly 1/5–1/10 of the mass.
- Carry over the steam-engine lessons that suit CO_2: compounding, variable cutoff, poppet valves, uniflow exhaust, a crosshead with a cooled distance piece, and a low-speed flywheel drive.

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08 Basis and assumptions

Parameter	Value used
Heat source	500,000 BTU/h (146.5 kW) logs, 800 °C flue, 150 °C stack with air preheater; CO_2 heater exit = CO_2 inlet + 30 K. Gives 110.8–114.5 kW to CO_2
Cooling / condensing	5 °C water/glycol; CO_2 condensing 10 °C at 45.0 bar, subcooled to 8 °C
Recuperator	Counterflow, 10 K minimum pinch
Purpose-built expander	80 % isentropic (70 % sensitivity); plunger transfer 92 %
Converted engine (route C)	65 % isentropic (70 % sensitivity); mechanical 88 % × hydraulic pump 90 %; CO_2 limited to 300–350 °C by cylinder oil
Pressurised crankcase (route B)	High side 61 bar (Δp ≈ 14 bar within old cylinder rating); 65 % expander
Low-pressure gas loop (route A)	5 → 15 bar, compressor 70 %, expander 65 %, 300 °C, recuperated
CO_2 feed pump	65 % isentropic, driven by hydraulic motor (85 %)
Reference steam engine	9 × 12 in horizontal, 125 psi, ~200 rpm, ≈ 39 ihp — representative, not a specific engine
Properties	CoolProp 8 (Span–Wagner CO_2)

Mass and size figures are order-of-magnitude estimates. This is a preliminary feasibility comparison, not a certified design.

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