

IPER Technology Workshop

sCO₂ Waste Heat Recovery for Industrial Applications

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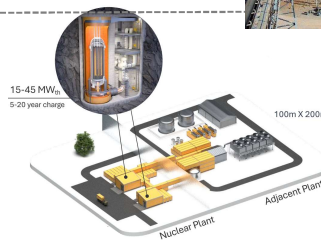
January 30-31, 2024, San Antonio, Texas



1. sCO₂ WHR Application

● sCO₂ is excellent for mid and high temperature applications providing high performance, compact size, zero emissions, and no water required.

Classification	Heat Source	Applications
Low Temperature (<400°C)	Biomass; Geothermal; various industrial	<ul style="list-style-type: none"> • Low levels of cycle efficiency • ORC / Geothermal • Low temperature industrial processes
HPS's Focus	Gas Turbine Engine WHR ¹⁾ ; Recips; Cement production	<ul style="list-style-type: none"> • Pipeline : Gas Turbine + sCO₂ Combined Solution • Industrial facilities • Ship Propulsion : COGES⁴⁾
	Steel Mills; Incinerators; SMR ²⁾	<ul style="list-style-type: none"> • 4th Gen Nuclear Power Gen System (sCO₂ preferred due to the Steam/Sodium contact risks) • SFR (Sodium-cooled Fast Reactor)
	CSP ³⁾	<ul style="list-style-type: none"> • 4th Gen Nuclear Power Generation System (alternative to Steam Turbine for higher temps) • High Temp Gas Reactor • Molten Salt Reactor
High Temperature (above 600°C)		<ul style="list-style-type: none"> • Renewable Energy : Power Block for CSP • Desert Area CSP alternative to Steam Turbine

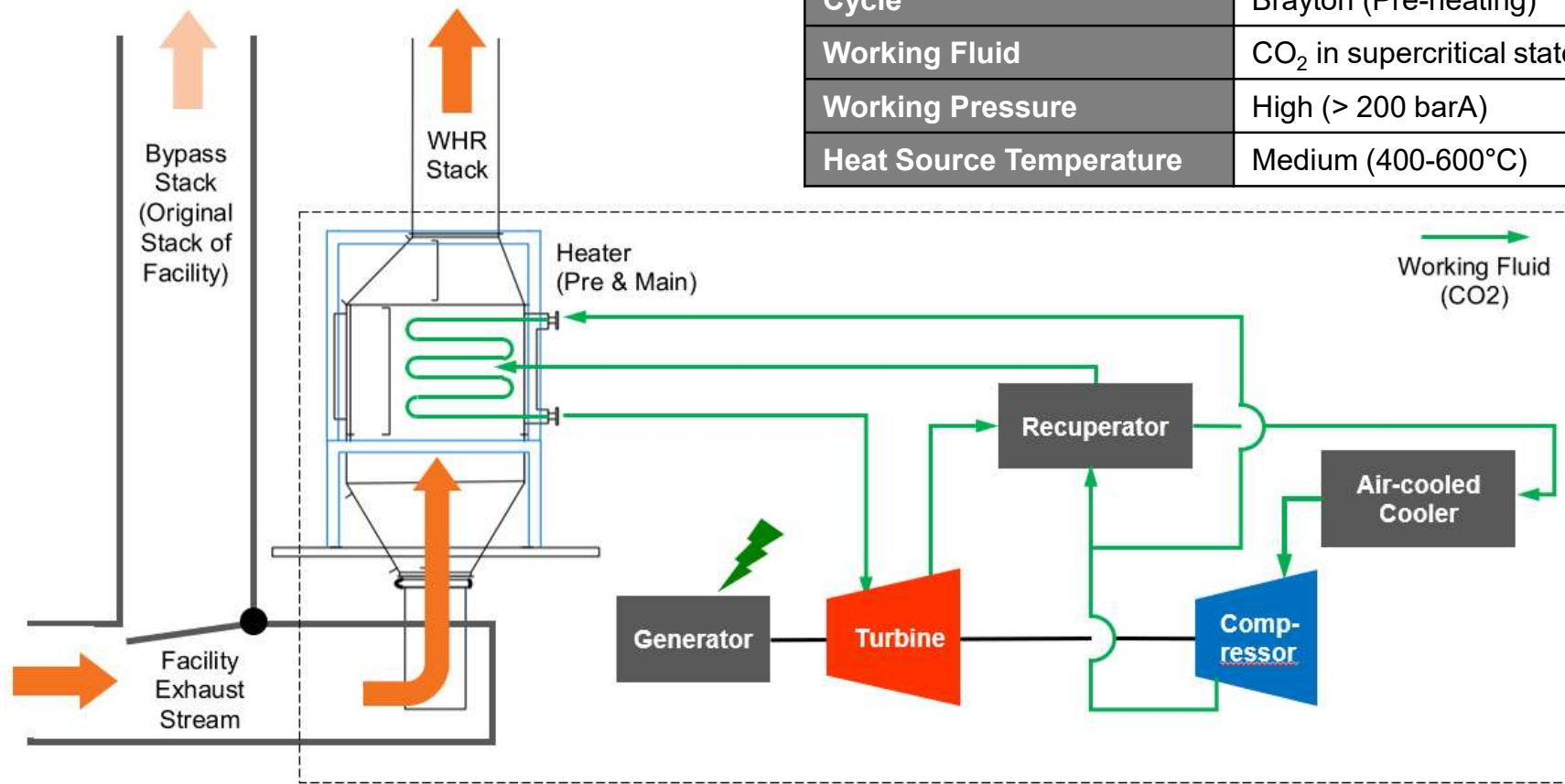


1) WHR : Waste Heat Recovery; 2) SMR : Small Modular Reactor; 3) CSP : Concentrated Solar Power; 4) COGES : Combined Gas turbine Electric and Steam

2. Mid Temperature – Gas Turbine WHR

- HPS's supercritical CO₂ (sCO₂) WHR power system recovers exhaust heat directly to the working fluid of CO₂ without requiring any heat transfer fluid. The CO₂ fluid is contained in a closed-loop system with no releases to the atmosphere. This system creates 100% emission free energy.

Feature	HPS sCO ₂ Power System
Cycle	Brayton (Pre-heating)
Working Fluid	CO ₂ in supercritical state
Working Pressure	High (> 200 barA)
Heat Source Temperature	Medium (400-600°C)



< HPS sCO₂ WHR Power System >

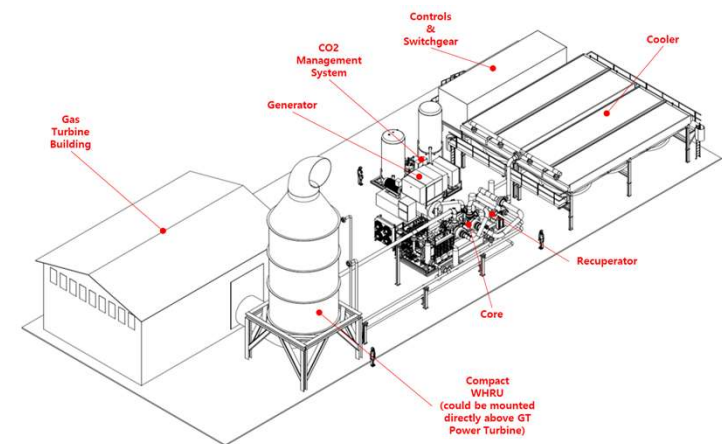
3. Mid Temperature – Gas Turbine WHR

Initial Considerations

- More than 65% of GT operating rate needed for viable economics
- Generally, GTs should be rated larger than 10,000 hp
- Preferred: Titan 130/250 Grade Power (17 – 25 MW)
- Space Available Near GT and Exhaust Stack
- General assumptions would be made for ambient site conditions, operating limitations, GT power rates, etc. in determining estimate WHR output and sizing

Estimated sCO₂ System Output

- 1) Energy: 31,536 – 47,304 MWh per year
- 2) Capacity: 4 – 6 MW
- 3) sCO₂ Unit Efficiency: 22 – 30%

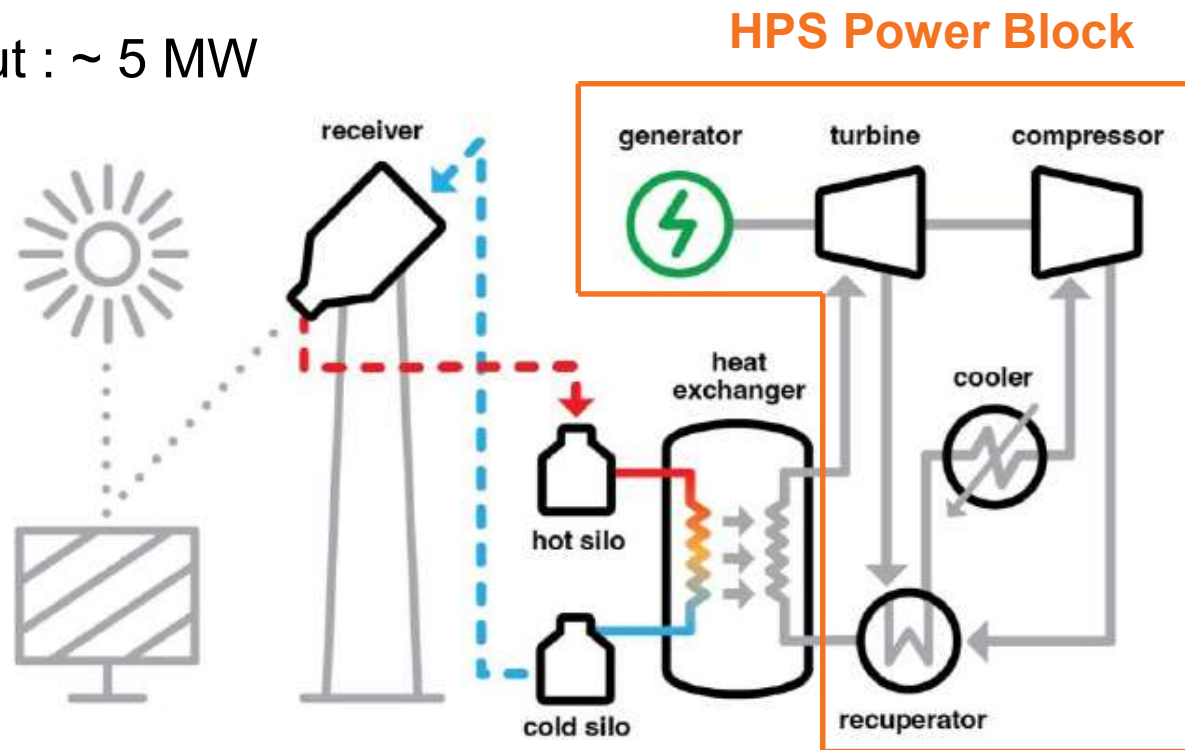


4. High Temperature – Concentrated Solar Power

- HPS provides skid-based sCO₂ power block with minimized footprint and high efficiency.

Heat Source Temp : ~ 600 °C

sCO₂ Power Output : ~ 5 MW



HelioPower™ Process

Source : Heliogen Presentation – 2023 ASME Turbo Expo Commercial Systems Panel

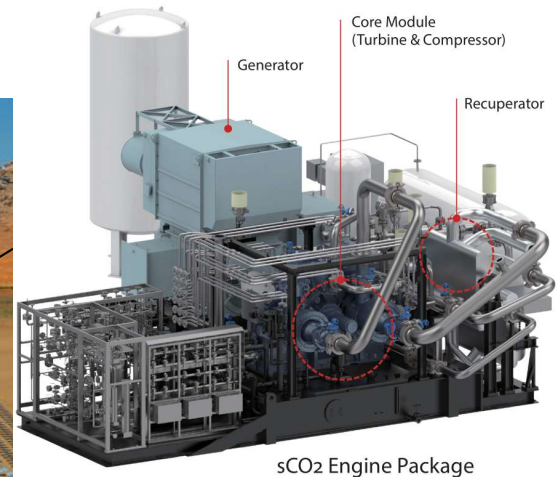
5. High Temperature – Concentrated Solar Power

● HPS executed a contract with Heliogen for the world's first 5MW sCO₂ (Dec 2021)

- Based on the successful outcome of DOE sCO₂ project, Heliogen released PO for supply of sCO₂ Power Block.



Heliogen's Capella Project Rendering



< HPS sCO₂ Power Block >

Heliogen aims to produce near always-available and transportable renewable energy – cost-effectively

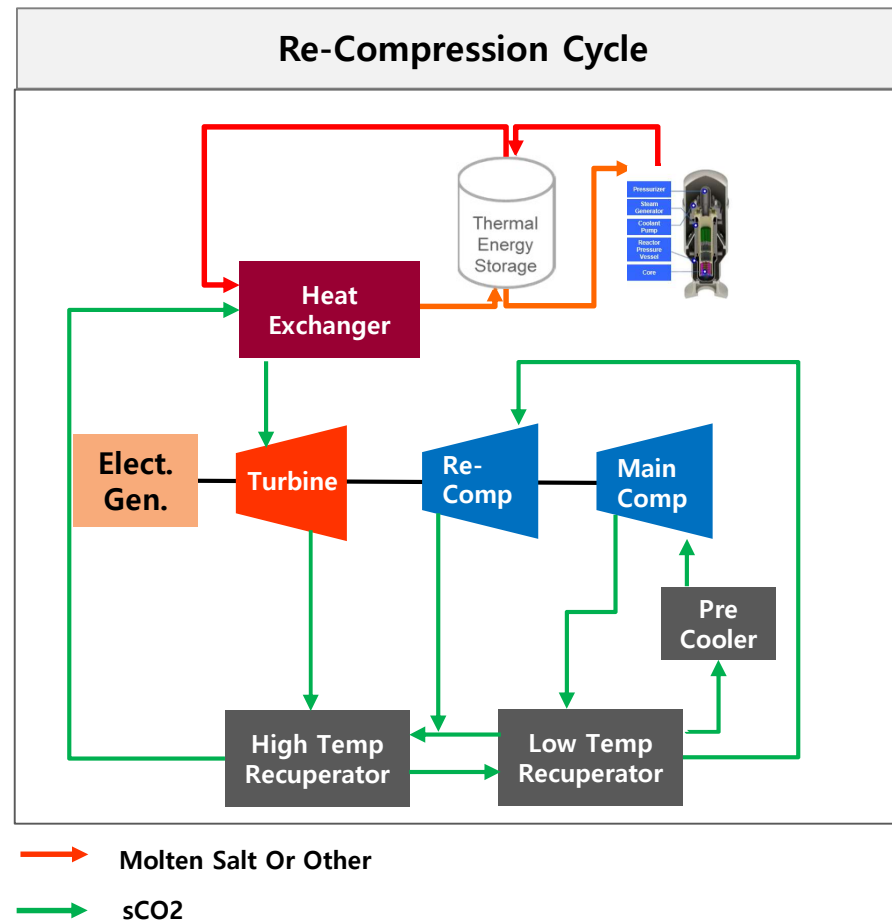
< Heliogen 5MW sCO₂ CSP Pilot Plant Rendering Image (US California) >

1) Image Source : Heliogen's company website, "Earnings Presentation, March 28, 2022" (Mojave, California)

6. High Temperature – SMR/MMR

4th Gen Nuclear Power Generation System – Small/Micro Modular Reactor

- Alternative to Steam Turbine for higher temp (700 – 800°C)
- sCO₂ preferred due to the Steam/Sodium contact risks
- sCO₂ power output can be optimized by flow rate and heat source temperature



Thank you!

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