Supercritical CO₂ Power Cycle Development and Commercialization: Why sCO₂ Can Displace Steam

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**The Echogen Cycle**

- Innovative usable (waste) heat to power generation cycle using supercritical CO₂ (sCO₂) in a closed loop
- Large scale industrial, utility and marine applications, including concentrating solar power (CSP)

**Power vs. Ambient Temperature**

- Echogen EPS100 performance is comparable to a double-pressure heat recovery steam system (DP-HRSG)
- An sCO₂ heat engine can provide up to 35% additional power output for stationary gas turbines

**The Advantages of sCO₂ Over Traditional Steam**

- **sCO₂ – Higher Power Density with No Phase Change**
- **Steam – Phase Change Limits Temperature and Cycle Efficiency**

**sCO₂ Systems Have Lower Installation and O & M Costs Compared to Heat Recovery Steam Systems**

- Installed cost per kilowatt for Echogen EPS100 is up to 40% less compared to HRSG
- sCO₂ requires a smaller system footprint with reduced balance of plant requirements
- HRSG requires higher O & M costs for water quality and chemical treatment of feedwater supply and condensate return systems which adversely impact HRSG availability, hardware reliability, and ability to tolerate cyclic operation

**Echogen Heat Engines Are Currently in Test and Production**

- 250 kW Demonstration System Completed Field Tests at AEP in 2010-11, and is Now Beginning Endurance Testing
- First Production Unit of the EPS100 6 to 8+ MWe System is Beginning Checkout Tests

**Levelized Cost of Electricity (LCOE) – The Key Performance Metric**

- LCOE accounts for all equipment, installation, operating, and maintenance costs over the lifetime of the system installation

- Expression for LCOE (USD $/kWh):

  \[
  \text{LCOE} = \frac{b \cdot C}{P \cdot H} + f \cdot h + OM \cdot h + m \cdot OM(n, b)
  \]

  Where:
  
  - \( b \) = Levelized carrying charge factor or cost of money
  - \( C \) = Total plant cost (USD $)
  - \( H \) = Annual operating hours
  - \( P \) = Net rated output (kW)
  - \( f \) = Levelized fuel cost (USD $/kWh)
  - \( h \) = Net rated efficiency of the combined cycle plant (LHV)
  - \( OM \) = Fixed O&M costs for baseload operation (USD $/kWh)
  - \( (n, b) \) = Variable O&M costs for baseload operation (USD $/kWh)
  - \( m \) = Maintenance cost escalation factor (1.0 for baseload operation)

- LCOEs analysed prepared for combined cycle gas turbine with steam or supercritical CO₂ heat recovery bottoming cycles
- Baseload operation: 8,000 hrs, 50 start/stops per year
- Cyclic operation: 3,500 hrs, 250 start/stop cycles per year
- Five system configurations studied at several price points for gas turbine fuel:
  - Simple cycle gas turbine (SCGT)
  - Combined cycle gas turbine (CCGT) with two-pressure HRSG bottoming cycle
  - Combined cycle gas turbine (CCGT) with Echogen EPS100 bottoming cycle
  - All combined cycles with wet-cooling (Steam wet and sCO₂ wet)
  - All combined cycles with dry-cooling (Steam dry and sCO₂ dry)

**Conclusions**

- High output power + low cost + low O&M = low LCOE
- Echogen EPS100 provides a 10 to 20% lower LCOE compared to traditional heat recovery steam for baseload and cyclic operation
- Lower installed cost for sCO₂ – smaller system footprint and reduced balance of plant requirements
- Lower O & M costs for sCO₂ – plant personnel not needed for water quality and treatment support functions typically found in a steam-based plants
- Growing trend to operate CCGT plants on as-needed, cyclic basis favors single-phase sCO₂ over steam – no hardware damage and premature life due to thermal fatigue and flow-assisted corrosion

- sCO₂ the clear solution for gas turbine heat recovery

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