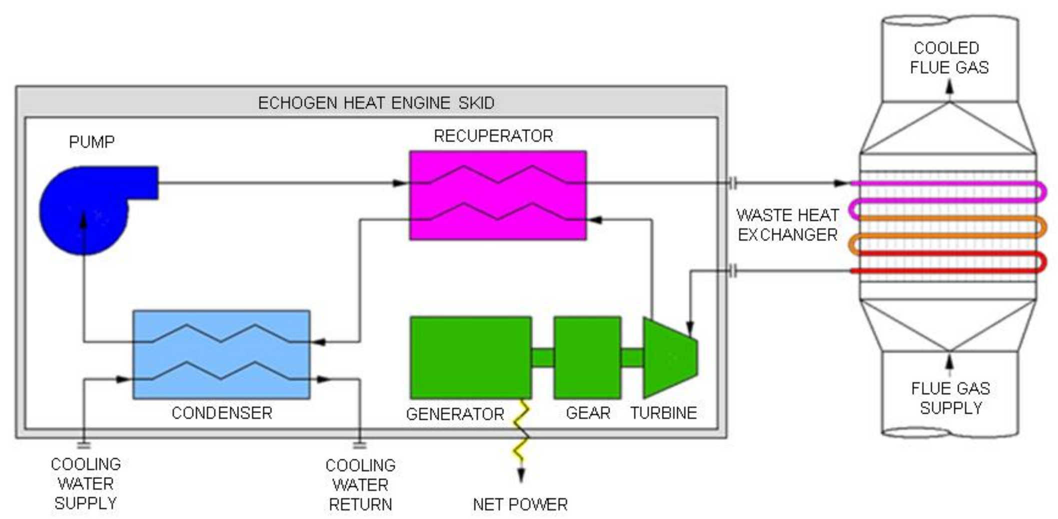
Supercritical CO_2 Power Cycle Development and Commercialization: Why sCO_2 Can Displace Steam

Michael Persichilli, Alex Kacludis, Edward Zdankiewicz, and Timothy Held

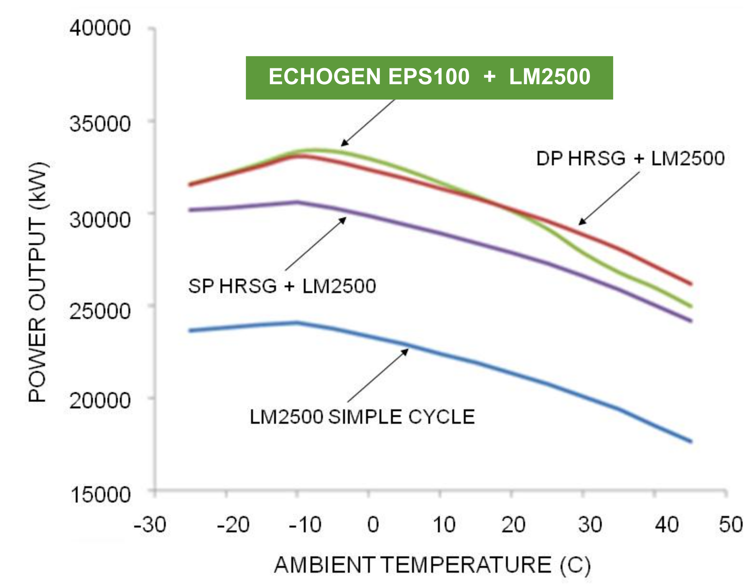
Echogen Power Systems LLC, Akron, OH USA

The Echogen Cycle



- Innovative usable (waste) heat to power generation cycle using supercritical CO_2 (sCO_2) in a closed loop
- Large scale industrial, utility and marine applications, including concentrating solar power (CSP)

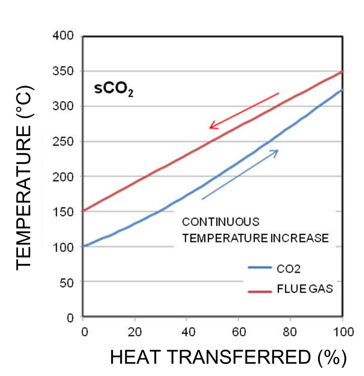
Power vs. Ambient Temperature

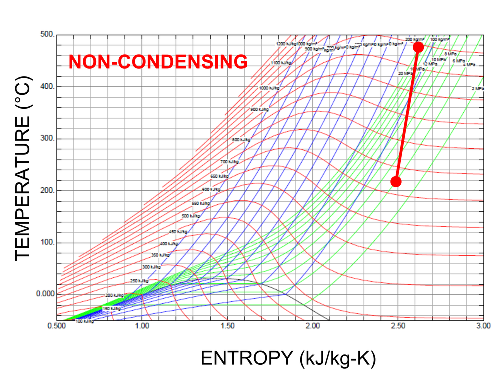


- Echogen EPS100 performance is comparable to a double-pressure heat recovery steam system (DP-HRSG)
- An sCO_2 heat engine can provide up to 35% additional power output for stationary gas turbines

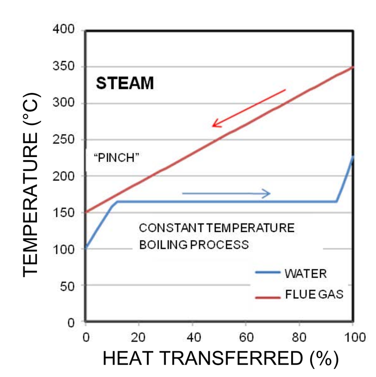
The Advantages of sCO_2 Over Traditional Steam

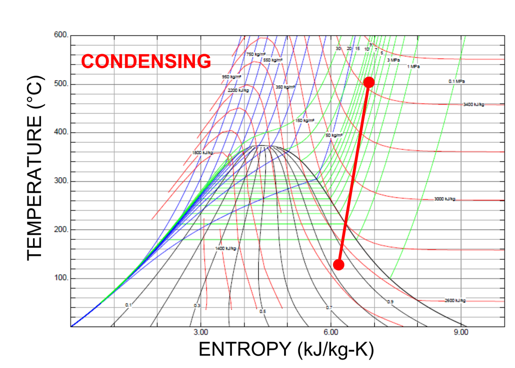
sCO_2 – Higher Power Density with No Phase Change



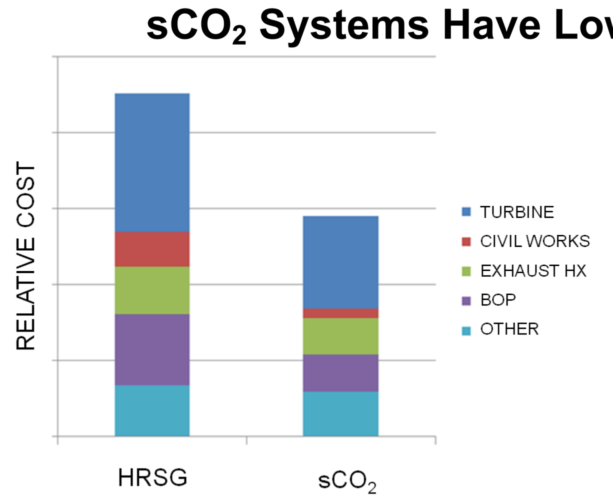


Steam – Phase Change Limits Temperature and Cycle Efficiency





sCO_2 Systems Have Lower Installation and O & M Costs Compared to Heat Recovery Steam Systems

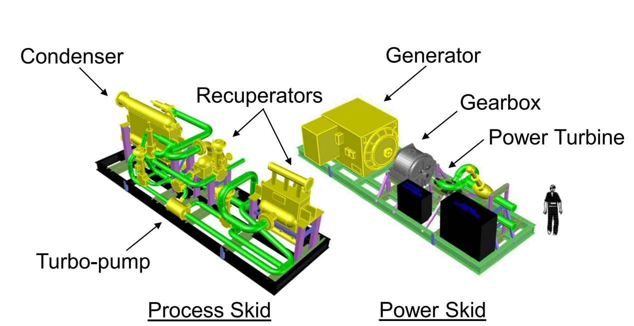


- Installed cost per kilowatt for Echogen EPS100 is up to 40% less compared to HRSG
- sCO_2 requires a smaller system footprint with reduced balance of plant requirements
- HRSG requires higher O & M costs for water quality and chemical treatment of feedwater supply and condensate return systems which 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



ECHOGEN power systems

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):

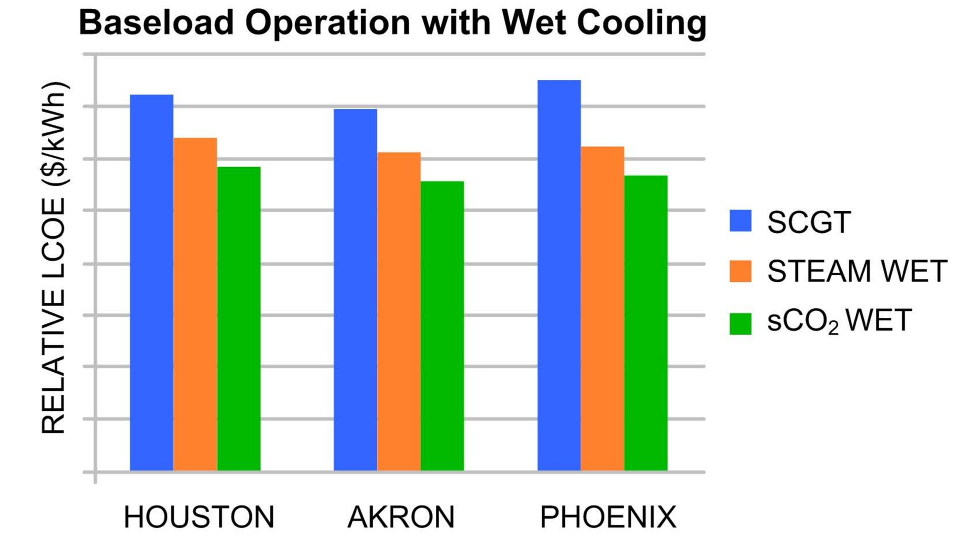
$$LCOE = (b \cdot C) / (P \cdot H) + f/h + OM/H + m \cdot OM(n, b)$$

Where:

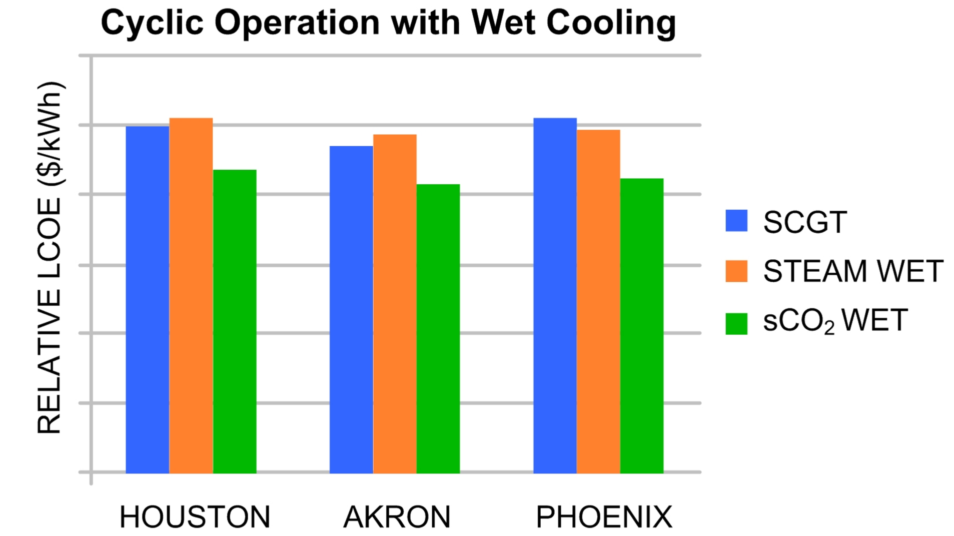
b	=	Levelized carrying charge factor or cost of money
C	=	Total plant cost (USD \$)
H	=	Annual operating hours
P	=	Net rated output (kW)
f	=	Levelized fuel cost (USD \$/kWh)
h	=	Net rated effciency of the combined cycle plant (LHV)
OM	=	Fixed O&M costs for baseload operation (USD \$/kWh)
(n, b)	=	Variable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

- LCOE analyses prepared for combined cycle gas turbine with steam or supercritical CO_2 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 sCO_2 wet)
  - All combined cycles with dry-cooling (Steam dry and sCO_2 dry)

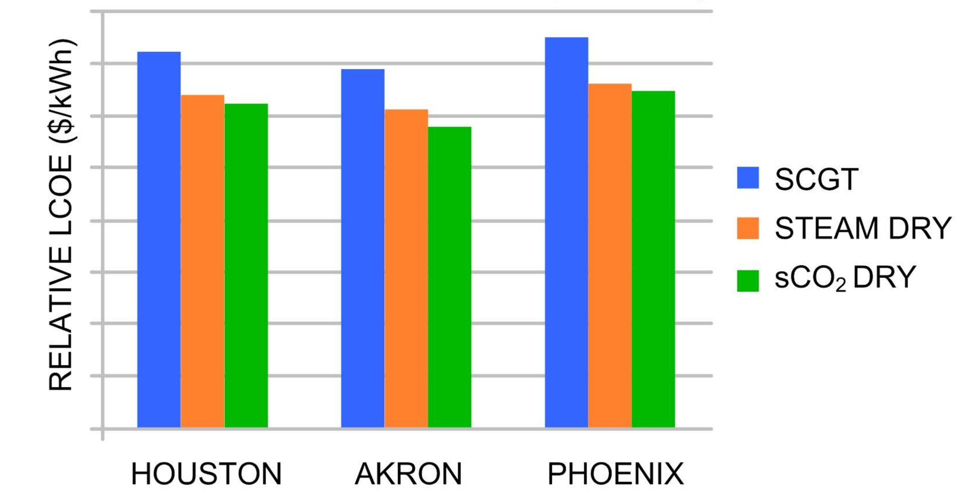
Baseload Operation with Wet Cooling



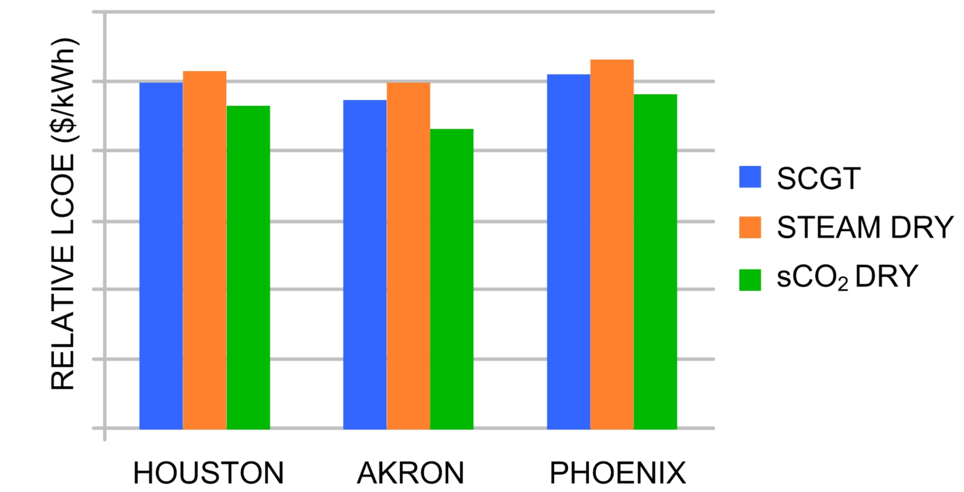
Cyclic Operation with Wet Cooling



Baseload Operation with Dry Cooling



Cyclic Operation with Dry Cooling



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 sCO_2 – smaller system footprint and reduced balance of plant requirements
- Lower O & M costs for sCO_2 – 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 sCO_2 over steam – no hardware damage and premature life due to thermal fatigue and flow-assisted corrosion

sCO_2 the clear solution for gas turbine heat recovery

For More Information, Contact:

Michael Persichilli
Vice President,
Business Development & Strategic Relationships

Office: 234-542-4379
Direct: 234-542-8034
Cell: 330-714-2540
Email: mpersichilli@echogen.com

www.echogen.com