Advanced Power Conversion Technologies and Role for Energy Storage

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sCO₂ Power Cycles

- Can achieve higher net efficiencies using a sCO₂ power cycle
  - 2–4% points better than a steam-Rankine cycle >300 MWe; 2–8% points <300 MWe
- Cycles are closed and heat is provided indirectly through a heater
- Expansion ratios are low at 4:1
- Turbines are 10 times smaller than a steam turbine with more flexibility
- Heat duty is high in sCO₂ power cycles, 5 times a steam-Rankine cycle
- Use of dry cooling to reduce water use
- Potentially lower costs
- Work on a wide range of temperatures and can be used for fossil, renewable, and nuclear, as well as waste heat recovery – fusion?

Compete directly with steam-Rankine and open air-Brayton cycles
Recompression Closed Brayton sCO₂ Cycle

Highest efficiency indirect-fired sCO₂ power cycle design
Echogen

Indirect-Fired sCO₂ Power Cycle

- “EPS 100” (7 MWe) tested for 100s of hours
- First commercial sCO₂ power cycle: CT bottoming cycle using 450°C waste heat
- Developing a 10-MWe demo for solid fuels with ~600–700°C turbine inlet temp
- Gaps include pressure drop in heat exchangers, material concerns at high temps, and cost
- Standalone systems could be commercial at 50–100 MWe scale by 2025–30

Most mature sCO₂ power cycle; EPRI involved in several projects
### Echogen: Techno-Economics

#### 90-MWe Coal Power Plant Using PRB

**DOE Project DE-FE0025959: “High-Efficiency Thermal Integration of Closed Supercritical CO₂ Brayton Power Cycles with Oxy-Fired Heaters”**

<table>
<thead>
<tr>
<th>Case number</th>
<th>Net Plant Eff (HHV basis)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>33.0%</td>
</tr>
<tr>
<td>2</td>
<td>34.3%</td>
</tr>
<tr>
<td>3</td>
<td>35.8%</td>
</tr>
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<td>4</td>
<td>40.0%</td>
</tr>
<tr>
<td>5</td>
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<tr>
<th>Net Power, MWe</th>
<th>Turbine Inlet Conditions</th>
<th>Net Efficiency, % (HHV)</th>
<th>Levelized Cost of Electricity, $/MWh</th>
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<tr>
<td>90</td>
<td>538°C / 10.6 MPa</td>
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More efficient than steam-Rankine and potentially less expensive
As variable renewable energy (VRE) grows, dispatchable resources are being shut down or operated flexibly:

- Primarily batteries provide new storage
- Other storage technologies being developed

Wind, solar, and batteries are inverter-based energy supplies – inertia limiting.

Gas, nuclear, coal, and solar thermal plants provide system inertia by synchronizing generators.

Conventional dispatchable resources further replaced with VRE, diurnal and multi-day energy storage needed:

- Higher VRE penetration
- Retrofit stranded assets with thermal energy storage (TES)
- Other non-battery types

Low-cost bulk energy storage, coupled with power cycles, provides synchronous power and system inertia.

> 80% low-carbon generation, primary energy sources stored in sufficient quantities for year-round power resilience:

- Bulk energy storage, e.g., large-scale TES (immediate use)
- Chemical fuel storage (hydrogen, ammonia) for seasonal energy shifting

Need for Energy Storage

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Need for Energy Storage
Energy Storage Technology Comparison

Battery

Non-Battery

Non-Battery

Battery

UPS

Grid Support

Energy Management

Power Quality

Load Shifting

Bridging Power

Bulk Power Mgmt.

1 kW

10 kW

100 kW

1 MW

10 MW

100 MW

1 GW

Discharge Time at Rated Power

Hours

Minutes

Seconds

System Power Ratings

UPS

Grid Support

Energy Management

Battery

Non-Battery

TES

Bad Creek

Pumped Hydro Storage

320x larger

TES has potential for more power, longer duration, and lower cost
Industrial heating load

- Gas unit
- Solar PV, wind
- Steam
- TES
- Concentrated solar
- Nuclear unit
- Fusion?
- Coal unit
- Gas unit
- Flue Gas
- Constant Steam
- Intermittent Steam
- Constant Steam
- Electricity
- Intermittent Electricity heat
- Electricity
- Steam/\text{\textit{sCO}_2}\text{ cycle}
- Grid services
- 24/7 demand

~1% per day thermal losses
No cycling degradation

No cycling degradation

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Potential TES Deployment

- By providing steam to TES during periods of low energy prices, the unit remains operational, avoiding cycling or shutdown and restart.
- When energy prices increase, steam from the boiler can be diverted to the steam turbine AND the TES units can provide steam to the turbines of the units with retired boilers.
- All units generate power when needed.

TES can be applied to any thermal plant (including fusion).
TES Examples

Key: Low-cost thermal media

Dispatchable, synchronous power over long periods (upto ~48 hours)